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November 23, 1998

NRA-98-HEDS-03

RESEARCH ANNOUNCEMENT

Microgravity Fluid Physics: Research and Flight Experiment Opportunities

Letters of Intent Due: .... January 15, 1999

Proposals Due: .... March 2, 1999

OMB Approval No. 2700-0087

MICROGRAVITY FLUID PHYSICS:
RESEARCH AND FLIGHT
EXPERIMENT OPPORTUNITIES

NASA Research Announcement
Soliciting Research Proposals
for the Period Ending
March 2, 1999

NRA-98-HEDS-03
Issued: November 23, 1998

Office of Life and Microgravity Sciences and Applications
Human Exploration and Development of Space (HEDS) Enterprise
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

NASA RESEARCH ANNOUNCEMENT
MICROGRAVITY FLUID PHYSICS:
RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

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NASA RESEARCH ANNOUNCEMENT

MICROGRAVITY FLUID PHYSICS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

This NASA Research Announcement (NRA) solicits proposals for flight experiments and for ground-based experimental and theoretical microgravity research in fluid physics. The fluid physics discipline represents a broad range of research areas ranging from heat and mass transfer to condensed matter physics. Descriptions of fluid physics research activities and interests are given in Appendix A.

Investigations selected for flight experiment definition must successfully complete a number of subsequent development steps, including NASA and external peer reviews of the proposed flight experiment, in order to be considered for a flight assignment. NASA does not guarantee that any investigation selected for definition will advance to flight experiment status. Proposals are sought for a number of upcoming flight opportunities. Investigations selected for support as ground-based research under the Microgravity Research Division (MRD) ground-based research program generally must propose again to a future solicitation in order to be selected for a flight opportunity.

Participation is open to U.S. and non-U.S. investigators and to all categories of organizations: industry, educational institutions, other nonprofit organizations, NASA centers, and other U.S. Government agencies. **Though NASA welcomes proposals from non-U.S. investigators, NASA does not fund Principal Investigators at non-U.S. institutions.** Proposals may be submitted at any time during the period ending March 2, 1999. Proposals will be evaluated by science peer reviews and engineering feasibility reviews. Late proposals will be considered if it is in the best interest of the Government.

Appendices A and B provide technical and program information applicable only to this NRA. Appendix C contains general guidelines for the preparation of proposals solicited by an NRA.

This announcement will not comprise the only invitation to submit a proposal to NASA for access to the reduced-gravity environment and is part of a planned sequence of solicitations inviting proposals in the disciplines of the microgravity program.

NASA Research Announcement Identifier:	**NRA-98-HEDS-03**
NRA Release Date:	**November 23, 1998**
Letters of Intent Due:	**January 15, 1999**
Proposals Due:	**March 2, 1999**
Selection Announcement:	**September 1999**

This NRA is available electronically and Letters of Intent should be submitted electronically via the Microgravity Research Division web page at:

http://microgravity.hq.nasa.gov/

Alternatively, Letters of Intent may be submitted via e-mail to the following address: loi@hq.nasa.gov
If electronic means are not available, you may mail Letters of Intent to the address given below.

Submit Proposals to the following address:

Dr. Gerald Pitalo
c/o Information Dynamics Inc.
Subject: NASA Research Proposal (NRA-98-HEDS-03)
300 D Street, S.W., Suite 801
Washington, D.C. 20024
Telephone number for delivery services: (202) 479-2609

NASA can not receive deliveries on Saturdays, Sundays or federal holidays.

Proposal Copies Required:...............15

Proposers will be notified by electronic mail confirming receipt of proposal approximately 10 working days after the proposal due date.

Obtain programmatic information about this NRA from:

Dr. Gerald Pitalo
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Obtain additional reference information at the following address:

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Selecting Official:

Director
Microgravity Research Division
Office of Life and Microgravity Sciences
and Applications
NASA Headquarters

Your interest and cooperation in participating in this effort are appreciated.

Arnauld E. Nicogossian, M.D.
Associate Administrator for
Life and Microgravity Sciences and Applications

APPENDIX A
NRA-98-HEDS-03

TECHNICAL DESCRIPTION

MICROGRAVITY FLUID PHYSICS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

A. BACKGROUND

The Human Exploration and Development of Space (HEDS) Enterprise, one of four National Aeronautics and Space Administration (NASA) strategic enterprises, conducts a program of basic and applied research using the reduced-gravity environment to improve the understanding of fundamental physical, chemical, and biological processes. The scope of the program, sponsored by the Microgravity Research Division (MRD), ranges from applied research into the effects of low gravity on the processing of various materials, to basic research that uses low gravity to create test conditions to probe the fundamental behavior of matter. This announcement is part of an ongoing effort to develop research in a specific scientific discipline, Microgravity Fluid Physics. The Division last released a NASA Research Announcement (NRA) for Microgravity Fluid Physics in 1996 and expects to continue to release NRAs in microgravity fluid physics every two years.

NASA has supported research in microgravity fluid physics for over three decades. An extensive research program supports theoretical and experimental investigations in ground-based laboratories. Many investigations are conducted using fluid physics research apparatus built to take advantage of the limited low gravity test times available in ground-based facilities such as the drop-towers at the NASA Lewis Research Center, or NASA's parabolic low gravity flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on fluid processes and phenomena.

In the MRD program, ground-based research has been used to gain a preliminary understanding of phenomena, and to define experiments to be conducted in the extended low gravity test times available in spacecraft in low-Earth orbit. MRD is developing several instruments to conduct fluid physics research that offer improved control and diagnostic capabilities over early experiments. These instruments are configured to investigate phenomena such as nucleate pool boiling, surface tension-driven flows, order-disorder transitions, granular media, and transport phenomena in critical systems. MRD also anticipates limited near-term flight opportunities for investigations capable of making use of existing hardware where no or minor modifications would be required.

MRD is also preparing for flight opportunities using International Space Station research instruments. MRD is currently studying the development of modular research instruments that can be configured (or reconfigured) to accommodate multiple experiments and multiple users. This is envisioned as an evolutionary program with the objectives of providing experimental data in response to increasingly sophisticated science requirements and of permitting the evolution of experimental approaches and technologies as needed for scientific investigations throughout the era of the International Space Station. This announcement is being released as part of a coordinated series of discipline-directed solicitations intended to span the range of the MRD program. Other MRD-supported solicitations are planned, as is this one, for periodic release over the next several years include:

Biotechnology
Combustion Science
Fundamental Physics
Materials Science.

B. RESEARCH ANNOUNCEMENT OBJECTIVES

This NRA has the objective of broadening and enhancing the MRD microgravity fluid physics program, the goals of which are described in Section II, through the solicitation of:

1. Experiment concepts which will define and utilize new instruments for space-based experiments in fluid physics with an emphasis on research concepts that can be accommodated by small, simple instruments;
2. Experimental studies which require the space environment to test clearly posed hypotheses, using existing or slightly modified instruments in space-based experiments to increase the understanding of fluid physics; and
3. Ground-based theoretical and experimental studies which will lead to the definition or enhance the understanding of existing or potential flight experiments in fluid physics with an emphasis on research that will provide a scientific foundation for technologies required by future human space missions.

Further programmatic objectives of this NRA include objectives broadly emphasized by the civil space program, including: the advancement of economically significant technologies; technology infusion into the private sector; enhancement of the diversity of participation in the space program, public education and outreach and several objectives of specific importance to the microgravity research program. These latter objectives include the support of investigators in early stages of their careers, with the purpose of developing a community of established researchers for the International Space Station and other missions in the next 10-20 years, and the pursuit of microgravity research that shows promise of contributing to economically significant advances in technology.

In support of the HEDS Enterprise goal to “Enrich life on Earth through people living and working in space,” individuals participating in the microgravity research program are encouraged to help foster the development of a scientifically informed and aware public. The microgravity research program represents an opportunity for NASA to enhance and broaden the public’s understanding and appreciation of the value of research in the microgravity environment of space. Therefore, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of the microgravity environment and microgravity fluid physics through formal and/or informal education opportunities. Where appropriate, supported investigators will be required to produce, in collaboration with NASA, a plan for communicating to the public the value and importance of their work.

C. DESCRIPTION OF THE ANNOUNCEMENT

With this NRA, NASA is soliciting proposals to conduct research in microgravity fluid physics, with an emphasis on experimental efforts that are sufficiently mature to justify near-term flight development and are of a scale that provides sufficient flexibility to be accommodated on various research platforms. The goals of the discipline along with some identified research areas of interest are described in Section II. Proposals describing innovative low gravity fluid physics research beyond that described herein are also sought.

NASA is currently developing several types of flight instruments for microgravity fluid physics research. Brief descriptions of the current and planned capabilities are given in Appendix B, Section I. NASA anticipates several near-term flight opportunities for investigations with requirements which can be met by existing apparatus with only minor modifications. Successful proposals for use of the existing apparatus will be funded for advanced definition studies which will produce a detailed Science Requirements Document (SRD). Authorization to proceed into flight development is contingent upon successful peer review of the experiment and SRD by both science and engineering panels. NASA does not guarantee that any experiment selected for definition which plans to use existing hardware will advance to flight experiment status.

NASA also encourages submission of experiment proposals for which none of the existing flight instruments is appropriate. NASA anticipates the development of new fluid physics research experiment apparatus for the International Space Station. The hardware descriptions included in Appendix B, Section I should be viewed as examples to allow researchers to consider capabilities that might meet their science requirements. However, researchers should not feel limited by these capabilities. Selected proposals requiring development of new capabilities will be funded for definition studies to determine flight experiment parameters and conditions and the appropriate flight hardware. The length of the definition phase will be based on the experiment requirements, but will normally range from 6 to 24 months and will culminate in the preparation of an SRD.

Authorization to proceed into flight development is contingent upon successful peer review of the SRD by both science and engineering panels. NASA does not guarantee that any experiment selected for definition which requires new instrument development will advance to flight experiment status. Investigations that do not proceed into flight development will normally be asked to submit a proposal for continuation of support at the conclusion of a typical four-year period of funding. Promising proposals which are not mature enough to allow development of a flight concept within two years of definition may be selected for support in ground-based research program. Investigations selected into the ground-based research program must generally propose again to a future announcement in order to be selected for a flight opportunity.

II. **MICROGRAVITY FLUID PHYSICS RESEARCH**

The microgravity fluid physics program encompasses a wide range of research in physics and engineering science, including studies of heat and mass transfer processes, fluid dynamics, and the physics of complex fluids.

Fluid physics is the study of the properties and motions of liquids and gases. Such studies arise from nature (e.g. in meteorology, oceanography, and living plants or animals) and technology (e.g. in biological, chemical and material processing, and fluid systems). Fluid phenomena span scales that range from nanometers to light years and constitute by their ubiquity one of the fundamental areas of science and engineering. The need for better understanding of fluid phenomena has created a vigorous, multi-disciplinary research community in fluid physics whose continuing growth has been marked by the steady emergence of new fields of relevance in both basic and applied science. Areas of technological and ecological importance like global atmospheric change, groundwater pollution, oil production, and advanced materials manufacturing often rely for their progress on advances in fluid physics. Scientists studying basic problems from chaotic systems to the dynamics of stars also turn to fluid physics for their models. Through the history of fluid physics, theory and experiment have maintained a synergetic relationship in building scientific knowledge. In recent years, research in fluid physics has been at the forefront in applying large-scale computational techniques to physical problems. The continuing advance of high-performance computing will drive new theoretical insights, which will spur a new generation of experimental fluid physics.

Microgravity research encompasses the phenomena related to gravitational fields (or equivalent accelerations with respect to inertial frames) whose magnitudes are but a small fraction of Earth's gravity. Gravity strongly affects many phenomena of fluid physics by creating forces in fluid systems that drive motions, shape boundaries, and compress fluids. Further, the presence of gravitational forces can mask effects that are ever present but comparatively small.

Fluid physics has a unique role in the NASA microgravity science program. Gravitational physics deals directly with the existence of gravity. Other scientific disciplines are interested in developing the potential of the microgravity environment as a research tool, and hope to create controlled conditions of fluid flow and heat and mass transport in specialized circumstances, e.g the growth of protein crystals, the solidification of a molten semiconductor, or the burning of liquid fuels. The goal of much of fluid physics research is simply to comprehend fundamental physical phenomena. In doing this, fluid physics contributes to seemingly distant fields of research by providing a fundamental framework of principles and basic understanding for flow and transport that specialists in other disciplines can apply to their problems. Fluid physics also has a crucial role in the space program in support of the effort to develop new technologies, or to adapt existing technologies (e.g. power generation, materials handling and processing, gas adsorption, and life support systems) for space operations or other extraterrestrial environments. A much sharper understanding of the detailed physics of these processes must be in hand before engineers can confidently design systems for use in non-Earth environments.

The MRD aims to support fundamental research and enabling technologies associated with space studies. It recognizes the need of supporting a vigorous theoretical and experimental ground-based program which supports space research and from which new ideas for space research can grow.

Studies of fluid phenomena and opportunities for research in space can be approximately classified according to their motivation, the known role of gravity, and the anticipated consequences of greatly diminished gravitational effects. Much research in microgravity fluid physics can be discussed within this conceptual structure: (1) how gravity, when eliminated or greatly reduced, results in putting to the fore effects otherwise masked, (2) the role of gravity, and how it produces fluid motions and compressions, and (3) how fluid-engineering systems perform in extraterrestrial environments.

A. UNMASKED PHENOMENA

When the influence of gravity on fluid behavior is diminished or removed, other forces can assume paramount roles. These forces can include capillary, thermocapillary, van der Waals forces, electrochemical/electrokinetic forces, Soret and Dufour effects, and contact line dynamics.

1. <u>Capillary Phenomena.</u> Surface tension on fluid-fluid interfaces can control the shapes of liquid bodies of even large scale. Small disturbances can shift dramatically the position of a liquid from one portion of the container volume to another, leading to configurational changes that can be important in the drainage of fuel tanks and generally in the area of fluid handling. Capillary instabilities can lead to the breakage of a liquid body into several pieces. Contact line characteristics can significantly affect configurations.

2. <u>Solid-Liquid Interactions.</u> Contact-line dynamics of fluid-fluid-solid trijunctions can control the coating of solid surfaces, the cooling of hot surfaces, and the behavior of vapor bubbles in nucleate boiling. Macroscopic contact angles depend on contact-line speeds and, hence, normally on flows driven by gravity. Liquid films less than 100 nm in thickness can rupture due to van der Waals attractions, creating new contact lines. Both fluid and thermal management in spacecraft are dependent on the behaviors of thin films and contact lines.

3. <u>Thermocapillary and Solutocapillary Phenomena.</u> When a fluid-fluid interface is subjected to a tangential gradient of temperature and/or species concentration, shear stresses are created in the

interface which drive bulk motions. Such surface effects can control the migration of droplets in bulk or along solid surfaces. They can enhance transport (compared to pure conduction) in large volume or in menisci. Steady motions can become unstable and lead to time-oscillatory behavior in containerless systems of materials processing. When a temperature gradient is imposed normal to an interface, the pure conduction state persists until a critical value of the gradient is exceeded, leading to Marangoni convection.

4. Coalescence and Aggregation Phenomena. Numerous phase-separation processes rely on coalescence or aggregation of dispersed phases to form continuous phases. Boiling, condensation, foam drainage and coarsening formation, and (Ostwald) "ripening" of solid precipitates are familiar examples. In droplet condensation and foam coarsening, relative motions caused by gravity, thermocapillary migration and van der Waals forces all contribute to foam drainage and film rupture. In precipitate ripening, large clusters grow at the expense of smaller ones.

5. Bubble or Droplet Migration. Momentum imparted to the liquid by the vapor bubble during growth can tend to draw the vapor bubble away from the surface. Thermocapillary forces, arising from the variation of the liquid-vapor surface tension with temperature, tend to move the vapor bubble toward the region of higher temperature. Bubble motion will be governed by which of these two effects prevails. The growth and dynamics of vapor bubbles that nucleate at a heater surface are determined by the mechanics of detachment at contact lines in the presence of heat transfer.

6. Crystal Growth. The growth of crystals from melt, vapor, or solution can be quite different in microgravity conditions than on Earth, because of reduced convection. This may result in a solid product with more uniform composition and structure. Moreover, the virtual absence of buoyancy-driven convection can result in a process controlled by molecular diffusion and, therefore, usually more predictable and amenable to modeling. The fundamental mechanisms governing crystal growth, particularly those that pertain to crystal-fluid-interface morphology (dendrites, cells, and the structure of in situ eutectic composites), are not well understood and often are masked by buoyancy-driven convection that is often unavoidable on Earth. Carefully designed experiments conducted in microgravity might guide choices among alternative theories.

7. Electrokinetics and Electrochemistry. Electrokinetics concerns transport phenomena involving charged fluid interfaces and their associated diffuse layer of space charge. The motion resulting from such processes is usually in response to an imposed electric field, which, in turn, offers a means of manipulating multiphase systems. External fields are also used in separation processes such as electrophoresis, isotachophoresis, and isoelectric focusing. Due to the presence of intrinsic charge on interfaces, electrical effects also play pre-eminent roles in the behavior of a myriad of colloidal systems, including many of biological origin. Electrochemistry deals with phenomena associated with the transfer of electrons at electrodes, resulting in chemical reactions. Although electrolysis reactions are the most familiar examples, there are a host of electrochemical synthesis processes where fluid motion effects transport processes. Electrochemistry and electrokinetics overlap whenever electrical double-layers are involved. Microgravity can have a role in issues where hydrodynamic considerations are involved in the electrochemical processes. Density differences may arise from Joule heating or from concentration changes as a consequence of electrochemical reactions. On the other hand, without natural convection, rates of electrochemical processes are typically diffusion-limited and, hence, low. In the electrochemical engineering practice, significant electrolyte circulation is often achieved through buoyancy effects due to the presence of gas bubbles in parts of the electrolyte. Limitations on earth-based experiments in electrokinetics and electrochemistry arise due to density differences in the fluids; these differences lead to buoyancy-driven bulk motion or sedimentation of particles.

8. Measurement of the Equilibrium and Transport Properties of Fluids. If all forms of convection are absent, other mechanisms such as diffusion become important. For example, a temperature gradient gives rise to mass transport, the Soret effect, and a concentration gradient gives rise to a temperature

gradient, the Dufour effect. Theoretical understanding of these diffusive effects in anything but very idealized model systems is hampered by the lack of experimental data for transport coefficients. These effects can be even more important in multicomponent systems in the Earth's gravitational field, but are very difficult to isolate from mass transfer. Some material properties of fluids could be measured more accurately, in principle, in the absence of gravity. This is particularly true of the equilibrium and transport properties of critical fluids, which experience diverging compressibilities at the critical point and consequently are greatly effected by hydrostatic pressure on Earth.

9. Dynamics of Fluid-Solid Interfaces. A key problem in materials preparation is the morphological instability of a front separating a liquid that is freezing into a crystalline solid. In the simplest case, there is thermodynamic equilibrium at the interface, and the dynamics is limited by diffusion of heat and solute. Then the local thermal and solutal gradient at the interface and the interfacial energy determines whether the interface remains planar (with a homogeneous solid being produced) or the interface becomes unstable to cellular or dendritic morphologies (with solute segregation in the solid). The absence of convection would allow careful test of the theory. Further, if buoyancy is absent, otherwise small effects such as interface kinetics and strong anisotropies of kinetics and surface energy (typically experienced in crystallization from vapor or solution) can have large effects.

10. Micromechanics of Cohesionless Granular Media. Fluid-like behavior is exhibited in nature by granular solids. The mechanics of such materials is governed largely by frictional-elastic contact forces, inertia, and gravity. There are a number of scientifically and technologically important phenomena, such as size segregation in rapid flow, unstable plastic deformation in slow flow, and seismic "liquefaction", whose origins are poorly understood. Experimentation in a reduced-gravity environment could allow one to isolate and understand the forces of non-gravitational origin and to eliminate density-gradients associated with gravity.

11. Multiphase Flow. Stratified gas-liquid flows that are maintained on Earth may not exist in a microgravity environment, leading to changes in the characteristics of pressure drop and heat transfer. Bubbly flow in pipes channels is strongly affected by gravity. Under microgravity conditions, the phase distributions should change substantially. Forced-convection nucleate boiling depends crucially on bubble dynamics which are strongly affected by gravity. All of the above require new criteria.

B. GRAVITY-DRIVEN PHENOMENA

The force of gravity has two direct effects. On one hand, it acts on fluid bodies to drive motions due to the relative buoyancy of phases of unequal density. It also acts on single phase fluids subjected to non-uniform thermal and solutal fields. On the other hand, it produces hydrostatic pressures that act on compressible materials. These two effects give rise to a number of important consequences for Earth-based fluid physics research. Studying the effects of gravity on processes can allow one to sort out gravity-driven from other phenomena such as those discussed above.

1. Convective Phenomena. On Earth, differences in density, resulting from inhomogeneity in temperature and/or composition, can cause an otherwise quiescent fluid to convect, thus giving rise to the transfer of momentum, heat, and mass. In experiments on the earth's surface, buoyancy-driven convective motion is typically orders of magnitude more rapid than the slow migration caused by molecular diffusion. Differences in surface tension on interfaces that arise because of temperature or concentration gradients along a fluid surface lead to thermocapillary or Marangoni convection. Studies of coupled systems with gravity can lead to means of understanding how one could extract the background behavior from the whole. Coupled buoyancy-driven and Marangoni convection is one case. Another is the effect of buoyancy-driven convection on the evolution of morphological instability in crystal growth. Most experiments on convective phenomena use transparent liquids, and provide limited information on the behavior of low Prandtl number liquids like metals and semiconductors. New means are needed to observe non-intrusively flow fields in optically opaque materials.

2. Compressional Effects. Complex materials, composed of materials with differing densities, are subject on Earth to hydrostatic gradients that compress or separate the constituents. Granular media exhibit pattern changes under stress. Colloidal and protein crystals are subject to sedimentation. Thin films in foams drain. Fundamental studies on Earth of complex materials determining the effects of gravity will indicate how successfully one can extract underlying phenomena from gravity-coupled behavior. Such understanding can lead to defining a role for microgravity experiments in a number of areas dealing with complex fluids.

C. RESEARCH FOR SPACE EXPLORATION

As one of NASA's four core Strategic Enterprises, the Human Exploration and Development of Space (HEDS) Enterprise is a catalyst to open the space frontier by exploring, using and enabling the development of space and to expand the human experience into the far reaches of space. Understanding of the fundamental role of gravity in the space environment in chemical and physical systems, however, is needed to achieve breakthroughs in science and enabling technology, and will be required should a national mandate for human exploration exist. The need for improved understanding of fluid phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline. The focus of the MRD program in the HEDS strategic Enterprise is to foster fundamental understanding, building a foundation of knowledge that can be applied to both Earth- and space-based technologies.

Gravity plays a dominant role in many of the systems, processes and technologies that are needed to achieve the exploration goals of the HEDS Enterprise. There are many specific scientific problems and issues which must be addressed prior to optimizing designs or developing more efficient systems for extraterrestrial exploration. These include physical and chemical processes in the areas of spacecraft systems, life support systems, use of in-situ resources and power generation in extraterrestrial environments and bio-fluids. Fundamental research is required to develop scaling laws for ranges of gravity levels between the microgravity environment of interplanetary travel to the partial gravity on Mars (3/8g) or the Moon (1/6g). Many areas of fluid physics research directly impact systems required for extraterrestrial exploration. As a result research in the following areas is sought to help answer fundamental questions underpinning the relevant technologies.

1. Dust Control and Granular Materials Handling Research. The control of contaminant dust in gases and the understanding of bulk granular materials behavior in variable gravity environments is extremely important for extraterrestrial surface operations and human safety. Since Mars has a thin, windy atmosphere in which dust is transported over the planet via storms, the dust is ubiquitous and without an efficient control technology it will permeate throughout habitats and machinery and will interfere with operation of equipment such as rovers, movable joints, and solar panels. In addition, the flow of a high-concentration dusty gas is not well understood, especially for charged particles. Research on the dust particles on Mars, their dynamics, deposition, abrasion effects, filtration and elimination is sought in order to improve the performance, health and safety of any Martian-based facility and the processing and use of the Martian atmosphere for developing (*in-situ*) fuels and other materials.

A second area of research is the handling of granular materials. Research needs to be conducted to understand the effects of gravity on the mechanics of granular materials to provide fundamental understanding of the problems associated with surface operations. The dynamics of granular materials impacts numerous technologies related to the utilization of regolith. These include geotechnical problems such as stability of rovers and habitats on Martian soil as well as the physics of transport of Martian soil for processing and habitat construction. Long-term research objectives include establishing scaling laws for soil studies of structures and surface operations which account for the difference in gravity between the Earth and Mars. Simulants, which behave similarly to the soils on Mars, could be utilized to test various engineering hypotheses using various techniques including laboratory tests, centrifuge experiments, and state-of-the-art analytical procedures. In the area of granular materials handling, research on bulk solid flow processes, such as storage, handling, processing and management of coarse grained materials and powders is sought as it affects the design of silos and conveyors.

2. Fluid Management Technology Research. As gravity is reduced from 1g, surface tension becomes of increasing consequence on large length scales. Thus bulk motion, such as of liquid propellants, as well as small-scale flow in heat pipes, heat exchangers, and fluid-purification systems is driven by the forces on fluid-fluid interfaces and at moving contact lines. Success at predicting boiling, cavitation, interface shapes, wetting and dewetting rates, in evaluating the effects of surface preparation and material selection, and in designing fluids-handling systems, may rely on replacing ad hoc assumptions about the microscopic mechanisms governing moving contact lines with accurate models. Interfacial instabilities can lead the qualitative changes in interfacial transport. In turn, the conditions for instability can be sensitive to solid/liquid surface energy, surface finish, g-jitter, surface contamination; all these need to be considered. Further, the conveyance of fluids in pipe and tanks can lead to problems of configuration control.

Knowledge of the mechanics of contact line motions under these circumstances, on Earth, in a low and in a microgravity environment would allow better understanding of these complex effects. As a result, proposals on interfacial phenomena as relate to transfer lines, pumps, liquefaction, and storage under low and zero gravity conditions under transient conditions are sought. Fundamental studies would yield a non-empirical approach to development and design of earth-based and extraterrestrial fluid management systems which is independent of the technique chosen.

3. Heat Transfer Technology Research. Under terrestrial conditions, gravity usually dominates the behavior of spacecraft thermal management systems, determining such important parameters as the heat transfer coefficient, pressure drop, residence time distribution, interfacial area, stability, and vibrational character of the flow. Design of heat transfer equipment depend on having sound physical models or empirical correlations. Because gravity produces dominant forces on Earth, existing models for the flow developed at normal gravity are expected to be inadequate for microgravity conditions. Of particular importance is the ability to predict the nature of boiling in the absence of buoyancy (which usually controls nucleate boiling) and of condensation, where gravity is usually employed to drain the condensate from the surface to maintain high transfer rates. Both of these processes depend critically on the flow patterns and distribution of shear in the fluid. Many of the most important, and yet least understood, problems in two-phase flow and heat transfer involve multidimensional phenomena. Thus, the development of mechanistic three-dimensional models of two-phase flow and heat transfer are essential for many applications of multiphase technology. Instabilities of thin liquid films may lead to temporal or spatial growth of surface waves, resulting eventually in rupture of the film. This can result in rapid dryout and overheating of the equipment. Very important is the scaling with gravity of these thermal phenomena, i.e., identification of boundaries where physics of phenomena changes with g level needs to be understood.

In concert with the objectives of item 1. above, the effects of Martian soil and dust on radiative properties of structures should be studied. For example, how will settled or suspended atmospheric dust affect the performance of equipment such as radiators.

4. Chemical Processes Research. A rapidly developing area relevant to exploration of other bodies in the solar system is In-Situ Resource Utilization (ISRU). Due to the cost constraints associated with carrying all the necessary resources for a sustained visit and return trip from either the Moon or Mars, utilization of natural resources at the landing site is receiving strong consideration. Basic physical and chemical methods will be applied to process local resources into usable commodities. In these scenarios the activities of the research community must result in fundamental understanding of operation of these processes in non-Earth environment to be able to develop efficient and reliable engineering systems. The chemical engineering community is well suited for extending the current Earth-based understanding of unit operations to the partial gravity environment on Mars.

Proposals are encouraged on efforts to advance the current understanding of unit operations in a partial gravity environment with the goal of improved process design and development. Examples of local resource utilization related physical and chemical processes where an understanding of the affects of variable g are needed include chemical reaction engineering, product and phase separation techniques and fluidized beds. Lunar regolith (soil) contains significant amounts of oxygen, chemically bound in various minerals, which would require processing to manufacture oxygen for use in propulsion and for life support systems. Similarly it is believed that Martian soil contains significant amounts of water which can be electrolyzed into oxygen and hydrogen again for propellants and life support. The Martian atmosphere will also be used for the production of oxygen, carbon monoxide and methane for propellants. Processes such as solid/gas and solid/liquid phase separation and transport phenomena in electrochemical systems are required for techniques such as regolith handling, fluidized beds, electrolysis, pyrolysis, sorption pumps and sabatier reactors.

An area in which the fluid physics community can make a contribution is in support of human space flight in its technological and biomedical requirements. Life support systems, particularly in the nearly closed designs required for long-duration missions, rely on gravity-dependent processes for atmosphere revitalization, water reclamation, and waste management. As with spacecraft systems, these systems incorporate two phase flow designs where a better fundamental understanding of the parametric dependence of multiphase systems on gravity and improvements in models would allow more confident engineering design.

5. Bio-Fluid Mechanics. Fluid dynamics research may help understand and eventually control some of the physiological consequences of the space environment. Efforts to yield a fundamental understanding of bio-fluid dynamics, such as transport phenomena in blood and ionic diffusion through membranes and porous media to apply towards counteracting the effects of weightlessness are encouraged.

III. **EXPERIMENT APPARATUS AND FLIGHT OPPORTUNITIES**

A. EXPERIMENTAL APPARATUS

In order to accommodate aspects of the research described in Section II, a number of pieces of flight hardware are being developed by NASA and its international partners. These are described in Appendix B, Section I. Section II of Appendix B lists the ground-based facilities that are available to support definition studies.

Flight opportunities under this NRA will be on sounding rockets, the Space Shuttle or the International Space Station (ISS). During sounding rocket flights five to ten minutes of microgravity (10^{-4} g) experimentation time is available. For the Shuttle opportunities, the experimental apparatus are located in the middeck or Spacehab, allowing direct human interaction, or in the cargo bay which does not permit such interaction. Residual acceleration levels on the order of 10^{-4} g are available in the Shuttle for limited periods of time. Flights range from 7 to 16 days in duration. The Space Acceleration Measurement System (SAMS) is expected to be available to measure and record actual accelerations at or near the apparatus for both Shuttle and ISS experiments. Considerable additional information on the Shuttle accommodations and capabilities can be found in the STS Investigators' Guide (see Bibliography). Experimental apparatus for the early utilization of the International Space Station will primarily be in facilities such as the Glovebox and Express rack (ISS versions of Shuttle middeck class experiments) followed by the Fluids Integrated Rack after the completed assembly of the ISS. A high-capacity communications network supports Shuttle and ISS payload operations. Downlink channels enable users to monitor their instrument status and science data streams in real time. An uplink channel enables them to act on that information. The effective use of these downlink and uplink capabilities enables telescience on a near realtime basis.

B. DIAGNOSTIC MEASUREMENTS

The capability to characterize science experiments in reduced-gravity is essential to scientific progress in this program. NASA, in ground-based normal and reduced-gravity studies, is developing techniques for enhancing imaging and visualization, and improving measurements of temperature, velocity, and particle-size distributions. As these techniques mature, those most required by investigators will be reviewed for space flight development as part of the future flight equipment capability.

C. FLIGHT OPPORTUNITIES

Missions available for this program may include several Shuttle flights, sounding rocket flights and missions on the International Space Station. These flight opportunities are dependent on the progress of the construction of the International Space Station. The complexity of the hardware required to complete the investigation may have a significant impact on the flight definition selection.

D. EXPERIMENT DEFINITION AND FLIGHT ASSIGNMENT PROCESS

Ground-based research is usually necessary to clearly define flight experiment objectives. This research may involve experimentation in NASA-provided ground-based facilities, including those which can provide a limited duration low gravity environment. (These facilities are described in Appendix B, Section II.) Successful proposals for flight opportunities will be supported for a ground-based definition phase before review for flight assignment. The amount of support (technical, scientific, and budgetary) and the length of the definition period (usually from 6 months to 2 years) will depend on the specific investigator needs and the availability of resources from NASA. However, in preparing their budget plan for this research announcement, all respondents should estimate their annual costs for four years.

Shortly after selection of projects for flight definition, NASA will initiate a process to identify fundamental technical feasibility issues. A small team of engineers and scientists at the NASA field centers will work with the Principal Investigator to translate requirements into the appropriate experiment technical requirements. The result is a systems engineering approach which prioritizes and links the facets of the experiment development process assuring that the objectives of the experiment can be met. The process will help determine whether there are any outstanding issues that would inhibit the success of the flight project, considering both technical challenges and required resources. At that point NASA may make a judgment as to whether a project will continue the flight definition process or revert to the ground-based program (see below).

1. <u>Near-Term Flight Opportunities.</u> Successful proposals for use of the existing instruments will be funded for a period of advanced definition work, after which time the investigator will generate a detailed SRD. The SRD, a detailed experiment description outlining the specific experiment parameters and conditions, as well as the background and justification for flight, must be prepared jointly by a NASA-appointed project scientist and the Principal Investigator and submitted for peer review. This formal review by both science and engineering panels will determine if space flight is required to meet the science objectives and if instrument capabilities can be provided to meet the science requirements. Following approval by the panels, subject to program resources, continuation support will be awarded and the hardware will be modified to meet the science requirements. NASA does not guarantee that any experiment selected for definition will advance to flight experiment status. Investigations with unresolved science or engineering issues at the review of the SRD may be placed in ground-based status with support of limited duration (normally from one to three years), and asked to submit a proposal to a subsequent solicitation for further support.

2. <u>Future Flight Opportunities.</u> Successful proposals for the development of new apparatus will be funded for a period of definition. The length of the definition period will be based on the experiment requirements, but will generally be from 6 to 24 months. At the end of the experiment definition phase,

the investigator will generate a detailed SRD. Following successful peer review of the SRD by science and engineering panels, the experiment will proceed into flight development and be considered for flight. As with opportunities for existing instruments, NASA does not guarantee that any experiment selected for definition will advance to flight development status, and the possibility exists that investigations may be placed in ground-based status, with continuing support from NASA for a limited period.

3. Ground-Based Definition Opportunities. Promising proposals for experimental research which are not mature enough to allow development of an SRD after two years of definition, and proposals for development of theory in areas of current or potential microgravity experiments, may be selected for support in the MRD ground-based research program. Ground-based studies are funded for periods of up to four years. A new proposal to a future announcement is currently required in order to be selected for a flight opportunity or to continue ground-based studies if appropriate. Proposals for development of new technologies for flight experiments that will provide new capabilities for fluid physics research are encouraged.

IV. PROPOSAL SUBMISSION INFORMATION

This section gives the requirements for submission of proposals in response to this announcement. The research project described in the typical proposal submitted under this announcement must be directed by a Principal Investigator who is responsible for all research activities and may include one or more Co-Investigators. Proposers must address all the relevant selection criteria in their proposal as described in Section VI and must format their proposal as described in this section. Additional general information for submission of proposals in response to NASA Research Announcements may be found in Appendix C.

A. LETTER OF INTENT

Organizations planning to submit a proposal in response to this NRA should notify NASA of their intent to propose by electronically sending a Letter of Intent (LOI) via the MRD Web Page:

http://microgravity.hq.nasa.gov/

Alternatively, Letters of Intent may be submitted via e-mail to the following address: loi@hq.nasa.gov

If electronic means are not available, you may mail Letters of Intent to the address given for proposal submission in the following section or Facsimile transmission is acceptable; the MRD fax number is (202) 358-3091.

The Letter of Intent, which should not exceed two pages in length, must be typewritten in English and must include the following information:

- The potential Principal Investigator (PI), position, organization, address, telephone, fax, and e-mail address.
- A list of potential Co-Investigators (Co-I's), positions, and organizations.
- General scientific/technical objectives of the research.
- The equipment of interest listed in this NRA, if appropriate.

The Letter of Intent should be received at NASA Headquarters no later than January 15, 1999. The Letter of Intent is being requested for informational and planning purposes only, and is not binding on the signatories. Institutional authorizations are not required. The Letter of Intent allows NASA to better match expertise in the composition of peer review panels with the response from this solicitation. In the Letter of Intent, investigators may request more detail on the capabilities of the specific equipment (Appendix B) that might be used to accomplish their scientific objectives and/or items listed in the Bibliography (Appendix A, Section IX).

B. PROPOSAL

The proposal should not exceed 20 pages in length, exclusive of appendices and supplementary material, and should be typed on 8-1/2 x 11 inch paper with a 10- or 12-point font. Extensive appendices and ring-bound proposals are discouraged. Reprints and preprints of relevant work will be forwarded to the reviewers if submitted as attachments to the proposal.

The guidance in Appendix C, Section D regarding the content of renewal proposals is not applicable to this NRA. Proposals should not rely on references to previous proposals for any information required for a complete proposal. **It is particularly important that proposers who seek to extend an existing NASA research activity that is relevant to this NRA must submit proposals that clearly identify and document achievements on their current effort and how it supports their request for additional sponsorship. Such follow-on proposals will be reviewed on an equal basis with all other submitted proposals.**

Fifteen copies of the proposal must be received at NASA Headquarters by March 2, 1999, 4:30 PM EST. Treatment of late proposals is described in Appendix C. Send proposals to the following address:

Dr. Gerald Pitalo
c/o Information Dynamics Inc.
Subject: NASA Research Proposal (NRA-98-HEDS-03)
300 D Street, S.W., Suite 801
Washington, D.C. 20024
Telephone number for delivery services: (202) 479-2609

NASA can not receive deliveries on Saturdays, Sundays or federal holidays.

Proposals submitted in response to this Announcement must be typewritten in English and contain at least the following elements (in addition to the required information given in Appendix C) in the format shown below, in the following order:

1. Form A (Solicited Proposal Application)
2. Form B (Proposal Executive Summary - replaces Abstract). The executive summary should succinctly convey, in broad terms, what it is the proposer wants to do, how the proposer plans to do it, why it is important, and how it meets the requirements for microgravity relevance
3. Form C (Budget For Entire Project Period Direct Costs Only)
4. Form D (Summary Proposal Budget - 1 copy for each year)
5. Table of Contents
6. Research Project Description containing the following elements:
   - Statement of the hypothesis, objective, and value of this research.
   - Review of relevant research.
   - Justification of the need for low gravity to meet the objectives of the experiment.
   - Description of the diagnostic measurements that would be required to satisfy the scientific objectives of any proposed low gravity experiments.

- Estimation of time profile of reduced-gravity levels needed for the experiment or series of experiments.
- A clear and unambiguous justification of the need to perform the experiment in space as opposed to ground-based reduced-gravity facilities.
- A description of a ground-based testing program that might be needed to complete the definition of the space flight experiment requirements in terms of experiment conditions, acceleration levels and durations, control and diagnostic measurement requirements, etc.
- Management plan appropriate for the scope and size of the proposed project, describing the roles and responsibilities of the participants

7. Prior Period of Support
   - **For follow-on proposals of ongoing MRD sponsored projects, a summary of the objective and accomplishments of the prior period of support, including citations to published papers derived from the existing tasks, must be included as part of the proposers justification for continued support.**
8. Appendices:
   - Supplementary budget information and budget explanations. The cost detail desired is explained below.
   - Summary of current and pending support for the Principal Investigator and Co-Investigators.
   - Complete current curriculum vita for the principal and Co-Investigators, listing education, publications, and other relevant information necessary to assess the experience and capabilities of the senior participants.
9. **3.5 inch computer diskette containing electronic copy of Principal Investigator's name, address, complete project title, and executive summary**

Proposal Cost Detail Desired. Sufficient proposal cost detail and supporting information will facilitate a speedy evaluation and award. Dollar amounts proposed with no explanation (e.g., Equipment: $58,000, or Labor: $10,000) may cause delays in evaluation or award. The proposed costing information should be sufficiently detailed to allow the Government to identify cost elements for evaluation purposes. Generally, the Government will evaluate cost as to reasonableness, allowability, and allocability. Enclose explanatory information, as needed. Each category should be explained. Offerers should exercise prudent judgment as the amount of detail necessary varies with the complexity of the proposal.

V. NRA FUNDING

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

For the purposes of budget planning, we have assumed that the Microgravity Research Division will fund up to 8 flight experiment definition proposals. These definition-phase proposals will be funded on an average of $175,000 per year. Approximately 70 ground-based study proposals will be funded, at an average of $100,000 per year, for up to 4 years. The initial fiscal year (FY) 2000 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts. **It is particularly important that the proposer realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year. Specifically, the resources required for the first year should not be overestimated.** The proposed budget for ground-based studies should include researcher's salary, travel to science and NASA meetings (for a flight investigation, roughly eight meetings per year with NASA should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead. During subsequent years, NRAs similar to this NRA will be issued, and funds are planned to be available for additional investigations.

VI. GUIDELINES FOR INTERNATIONAL PARTICIPATION

NASA accepts proposals from all countries, although this program does not financially support Principal Investigators in countries other than the U.S. Accordingly, proposals from non-U.S. entities should not include a cost plan. Non-U.S. proposals and U.S. proposals which include non-U.S. participation, must be endorsed by the appropriate government agency in the country from which the non-U.S. participant is proposing. Such endorsement should indicate that:

1. The proposal merits careful consideration by NASA
2. If the proposal is selected, sufficient funds will be made available from the country from which the non-U.S. participant is proposing, to undertake the activity as proposed.

Proposals, along with the requested number of copies and Letter of Endorsement, must be forwarded to NASA in time to arrive before the deadline established for this NRA. All proposals must be typewritten in English. All non-U.S. proposals will undergo the same evaluation and selection process as those originating in the U.S.

Sponsoring non-U.S. agencies may, in exceptional situations, forward a proposal directly to the address given on Page iv of the first section of this announcement if review and endorsement is not possible before the announced closing date. In such cases, an accompanying letter should indicate when a decision on endorsement can be expected.

Successful and unsuccessful proposers will be notified by mail directly by the NASA program office coordinating the NRA. Copies of these letters will be sent to the sponsoring government agency. Should a non-U.S. proposal or U.S. proposal with non-U.S. participation be selected, NASA's Office of External Relations will arrange with the non-U.S. sponsoring agency for the proposed participation on a no-exchange-of-funds basis, in which NASA and the appropriate government agency will each bear the cost of discharging its respective responsibilities. Depending on the nature and extent of the proposed cooperation, these arrangements may entail:

1. A letter of notification by NASA
2. An exchange of letters between NASA and the sponsoring government agency
3. An agreement or memorandum of understanding between NASA and the sponsoring government agency.

VII. EVALUATION AND SELECTION

A. EVALUATION PROCESS

The evaluation process for this NRA will begin with a scientific and technical external peer review of the submitted proposals. NASA will also conduct an internal engineering review of the potential hardware requirements for proposals that include flight experiments. The external peer review and internal engineering review panels will be coordinated by the NASA Enterprise Scientist for Fluid Physics. Consideration of the programmatic objectives of this NRA, as discussed in the introduction to this Appendix, will be applied by NASA to ensure enhancement of program breadth, balance, and diversity; NASA will also consider the cost of the proposal. The MRD Director will make the final selection based on science panel and programmatic recommendations. Upon completion of all deliberations, a selection statement will be released notifying each proposer of proposal selection or rejection. Offerers whose proposals are declined will have the opportunity of a verbal debriefing with a NASA representative regarding the reasons for this decision. Additional information on the evaluation and selection process is given in Appendix C.

B. EVALUATION FACTORS

The following section replaces Section J of Appendix C. The principal elements considered in the evaluation of proposals solicited by this NRA are: relevance to NASA's objectives, intrinsic merit, and cost. Of these, intrinsic merit has the greatest weight, followed by relevance to NASA's objectives, which has slightly lesser weight. Both of these elements have greater weight than cost. Evaluation of the intrinsic merit of the proposal includes consideration of the following factors, in descending order of importance:

1. Overall scientific or technical merit, including evidence of unique or innovative methods, approaches, or concepts, the potential for new discoveries or understanding, or delivery of new technologies/products and associated schedules;
2. Qualifications, capabilities, and experience of the proposed Principal Investigator, team leader, or key personnel who are critical in achieving the proposal objectives;
3. Institutional resources and experience that are critical in achieving the proposal objectives;
4. Overall standing among similar proposals available for evaluation and/or evaluation against the known state-of-the-art.

The peer review panel will assign each proposal a numerical merit score from 1 (worst) to 9 (best) based on the above factors. The score assigned by the peer review panel will not be affected by the cost of the proposed work nor will it reflect the programmatic relevance of the proposed work to NASA. However, the panel will be asked to include in their critique of each proposal any comments they may have concerning the proposal's budget and relevance to NASA.

The following questions should be kept in mind by proposers when addressing the relevance to NASA's scientific and programmatic objectives:

1. Is microgravity of fundamental importance to the proposed study, either in terms of unmasking effects hidden under normal gravity conditions or in terms of using gravity level as an added independent parameter?
2. Do the issues addressed by the research have the potential to close major gaps in the understanding of fundamentals of fluid physics processes?
3. Is there potential for elucidation of previously unknown phenomena?
4. Is the project likely to have significant benefits/applications to ground-based as well as space-based operations involving fluid physics processes?
5. Are the results likely to be broadly useful, leading to further theoretical or experimental studies?
6. Can another project in the specific sub-area be justified in terms of limited resource allocation?
7. Is the project technologically feasible, without requirements for substantial new technological advances?
8. How will this project stimulate research and education in the fluid physics area?

9. How does the projected cost/benefit ratio compare with other projects competing for the same resources?
10. What is the potential of this project in terms of stimulating future technological “spin-offs”.
11. Are there strong, well-defined linkages between the research and HEDS goals? (See Section II,C of this Appendix).

IX. **BIBLIOGRAPHY**

Background materials are available to NRA proposers upon written request to:

Dr. Bhim Singh
MS 500-102
Microgravity Science Division
Lewis Research Center
National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, OH 44135-3191
(216) 433- 5396
bhim.singh@lerc.nasa.gov

Documents and Web Sites that may provide useful information to proposers are listed below:

1. Office of Life and Microgravity Sciences and Applications (OLMSA) Homepage at NASA Headquarters, http://www.hq.nasa.gov/office/olmsa/
2. Microgravity Research Division Homepage at NASA Headquarters, http://microgravity.hq.nasa.gov
3. Microgravity Research Program Office Homepage at NASA Marshall Space Flight Center, http://microgravity.msfc.nasa.gov.
4. Microgravity Research Facilities and Fluid Physics Flight Experiments, Microgravity Science Division Homepage, NASA Lewis Research Center, http://zeta.lerc.nasa.gov
5. STS Investigators' Guide, NASA Marshall Space Flight Center.
6. Second Microgravity Fluid Physics Conference Proceedings, NASA Conference Proceedings 3267, June 1994.
7. Third Microgravity Fluid Physics Conference Proceedings, NASA Conference Proceedings 3338, June 1996.
8. Fourth Microgravity Fluid Physics Conference Proceedings, National Center for Microgravity Research on Fluids and Combustion, August 1998, http://www.ncmr.cwru.edu/events/conf-proceedings.html
9. Microgravity Science and Applications Program Tasks and Bibliography, 1997, http://peer1.idi.usra.edu/peer_review/taskbook/micro/mg97/mtb.html
10. Workshop on Research for Space Exploration: Physical Sciences and Process Technology, NASA Conference Publication CP-1998-207431, http://LeTRS.lerc.nasa.gov/cgi-bin/LeTRS/browse.pl?1998/CP-1998-207431.html
11. NASA Reduced-Gravity Carrier Options for Microgravity Experiment Operations, http://peer1.idi.usra.edu/peer_review/prog/CarrierOptions.pdf

APPENDIX B
NRA-98-HEDS-03

HARDWARE AND FACILITY DESCRIPTIONS

The Microgravity Research Division (MRD) is pursuing a program for the development of Sounding Rocket, Space Shuttle and International Space Station (ISS) payloads that can be configured (or reconfigured) to accommodate multiple users. This evolutionary program is expected to meet the science requirements of increasingly sophisticated microgravity investigations and to permit the eventual development of experiment payload technologies for research throughout the era of the ISS.

I. CURRENT AND PLANNED FLIGHT HARDWARE

The experimental apparatus described in this section have been developed or are under development for flight on Sounding Rockets, Space Shuttle missions and/or the ISS. Minor modifications of the current hardware may be possible to make it more versatile and to accommodate users and experiments other than those for which it was originally designed. Availability of the instruments described here, with or without modification, is contingent upon the availability and allocation of resources, and cannot be guaranteed at this time.

More detailed descriptions of the current flight hardware may be requested in the Letter of Intent described in Appendix A, Section V.

A. ISS FLUIDS INTEGRATED RACK (FIR)

The International Space Station (ISS) United States Laboratory Module will support the Fluids and Combustion Facility (FCF) under development at the Lewis Research Center. The FCF is a modular, multi-user, microgravity science facility which will occupy three powered payload instrumentation racks plus the equivalent volume of one unpowered stowage rack. Together the three racks will provide the fundamental physical and functional infrastructure necessary to perform combustion science, fluid physics, and adjunct science experiments on-board the ISS.

The Fluids Integrated Rack (FIR) will be the second FCF rack and is anticipated to be launched in year 2003, following the Combustion Integrated Rack scheduled for the ISS in the year 2002. It will be equipped to operate as a single integrated rack to provide the initial set of Principal Investigators with the functionality required to perform their experiments with enhanced performance upon delivery of the third rack. The FIR is based on a “carrier” approach that provides common services needed by nearly all fluids physics researchers to minimize the hardware required to be developed and launched for each experiment. Since a majority of hardware is reused, the FIR concept saves both development costs and total upmass required to perform the experiments. The FIR system has the following subsystems determined to be essential to perform the microgravity fluid physics experiments:

ISPR/Structural Subsystem: The FIR Rack utilizes the NASA International Space Station Rack (ISPR) as the basic structure for payload equipment to provide an enclosed volume of approximately 1.6 m^3 and supporting 700 Kg of mass. The ISPR has a bowed back to provide maximum volume if properly utilized and mounts directly into the ISS US Lab. The front of the ISPR will be sealable via a door to prevent exchange of dust, particulates, and other materials with the US Lab cabin, provide containment of the air for thermal control and fire suppression, and also to minimize acoustic and thermal impacts from/to other US Lab users.

Active Rack Isolation System: FIR experiments will be sensitive to motion and vibration induced by other ISS systems, users, the crew and associated ISS activities, such as docking, EVA, thruster firings, etc. In order not to disturb these experiments, ISS designers have developed the Active Rack Isolation System (ARIS) to isolate the ISPR from major mechanical disturbances that might occur on the ISS, essentially acting as a shock absorber. ARIS provides the unique ability to 'float' an entire ISPR and isolate it from external vibration sources with minimal encroachment on internal rack volume through an electronic sensing and control of eight electro-mechanical rack isolation actuators. ARIS provides rack level attenuation of on-orbit low frequency/low-amplitude mechanical vibrations transmitted from the US Lab to the FIR rack when science operations are conducted.

Optics Bench: The FIR provides the Principle Investigator (PI) with a laboratory style "Optics Bench" on which an experiment will be configured. The optics bench features the capability to remove and replace different PI specific experiment packages. This design offers the advantage of utilizing the surface area on both sides of the bench and the entire ISPR volume. The optics bench folds down to allow access to science support packages located on the back side.

The optics bench spans two thirds of the ISPR with dimensions of 86.5 x 124.5 cm (Width x Length) with a distance of 50 cm from the surface of the plate to the door. The optics bench provides nearly one square meter of surface area on the front for which experiment hardware may be configured. The plate on the front will provide an optical precision alignment surface and a stable thermal environment. This front optics plate serves as the mounting platform for the optics, samples, and experiment-specific packages. The back of the optics bench is dedicated to mounting several multi-function, non-intrusive optical diagnostics packages, and science avionics support packages to be described below. The diagnostic and avionics packages mounted on the back generate the most heat and are thus isolated to provide a better temperature-controlled environment for the science investigations.

Command and Data Management Subsystem: The FCF FIR Command and Data Management Subsystem (CDMS) includes all hardware and software to provide command, control, health and status monitoring, data acquisition, data processing, data management, timing and crew interface functions for the FIR. The FIR CDMS consists of three major packages: the Input/Output Processor (IOP), the Fluids Science Avionics Package (FSAP), and the Image Processing Package (IPP). The overall approach to the CDMS development is to utilize commercial off-the-shelf computer cards and associated support electronics to the extent practical.

The FIR's master control is provided by the Input/Output Processor (IOP) which provides command processing, control, resource allocation, data processing, caution and warning, software and data table upload and timing functions. The IOP will perform data acquisition of system, environmental and ancillary sensor data to provide rack health and status information. In addition, the IOP will process and transmit data in support of the fluids science including experiment sequencing, and control of predetermined functions. The IOP will function as the rack interface to the ISS by supporting the High Rate Data Link (HRDL), Ethernet, and MIL-STD-1553 interfaces.

The Fluids Science Avionics Package (FSAP) is a data acquisition and control package that will provide an enhanced set of science I/O, controllers, and signal conditioning capable of supporting a wide array of fluid science categories. The FSAP will provide closed loop control of the science experiment packages that include controllers for motion and temperature, support of motorized positioners and Thermo Electric Coolers (TEC), and interfaces for specialized devices such as Photomultiplier Tubes and Avalanche Photodiodes. Signal Conditioning will also be provided to support measurement devices such as thermocouples and transducers to measure pressure, strain, force, and flow rates. Additionally, the FSAP provides storage of the acquired data and is capable of transferring the data to the IOP for subsequent downlink.

The FIR will support the capability of providing extensive image acquisition, processing and management, as is typically required for fluids physics experiments. There will be one Image Processing Package (IPP) housing two Image Processing and Storage Units (IPSU) to provide this capability. The IPP provides the image capture and processing for two high-resolution digital cameras. Each camera interface consists of a PowerPC based single board computer, a MIL-STD-1553B communications interface, an Ethernet communications interface, image collection, processing, and memory cards, and a removable 9 GB hard drive of which 7 GB will be available for image storage. The IPSU will be capable of collecting data at 40 Mbytes / second nominally. Data can be passed from IPSU memory (256 MB) to a more permanent storage area or directly to the IOP for downlink. The IPSU will store video data in a digital format. The data acquired will be compressed (if required) to reduce memory and transfer bandwidth and processed to support closed loop control scenarios such as focus, zoom, and particle auto-track capability.

Electrical Power Subsystem: The FIR Electrical Power Subsystem (EPS) consists of an Electrical Power Control Unit (EPCU), cables from ISS to the EPCU, harnesses from the EPCU to user/facility loads, and associated interface connectors. Electrical power from the ISS is controlled and distributed throughout the FIR by the EPCU Package. The EPCU performs electrical power conditioning, optimized distribution, switching, and fault protection for the FIR. The EPCU is capable of regulating the voltage to 28 VDC at an efficiency of 92%. The EPCU switches 48 different channels and current limits each channel to 4 amps. For crew safety, all twelve EPCU front panel output connectors are 28 VDC. Except for length, all 28 VDC four circuit cables are interchangeable and connect to the EPCU front panel connectors which are identical for reconfiguration flexibility. If necessary, limited 120 VDC from the EPCU rear panel connector can be supplied to a large (500 W to 1500 W) single load.

FIR Diagnostics: High resolution digital cameras and associated lenses will be provided as the standard means of image acquisition in the FIR. Utilizing cameras, motorized lenses, configurable mirrors and support equipment, the imaging packages will provide a feature-rich environment for acquiring high-quality digital images. Also, the FIR will be capable of supporting an analog camera and converting the images to digital. Three cameras (two digital, one analog) have been identified as standard FIR resources that consist of two monochromatic (black and white) high resolution (1024 x 1024 12-bit pixels, 30 frames per second) digital cameras and one analog color camera to achieve color images. One high-resolution camera package will provide x-y translation particularly for microscopic alignment. An upgrade is being designed for a high frame rate camera capable of acquiring images at up to 1000 frames per second or greater.

The cameras will accommodate various fixed focus and motorized zoom lenses that can be interchangeable between the cameras. Two unique primary lenses will provide a nominal field of view of 10 cm by 10 cm when used with the high resolution cameras and will have motorized focus capability. With special lens attachments, the fields of view of these lenses will be 2.5 cm by 2.5 cm, 5 cm by 5 cm, and 7.5 cm by 7.5 cm. These attachments will be small and easily changed without removing the motorized primary lens. The f-stop will be variable from f/1.9 to f/11. A third lens will provide fields of view of 2.6 mm by 2.6 mm, 5.6 mm by 5.6 mm, 10.4 mm by 10.4 mm, and 12.5 mm by 12.5 mm with resolutions (twice the distance between pixel centers) of 4, 8.5, 16, and 18.8 micrometers, respectively. An additional lens will provide a 10 cm by 10 cm filed of view for the color camera. Optical component mounting is designed for easy astronaut changeout and reconfiguration. In addition, the PI has the option to replace a camera lens with a specific lens to accommodate specific experimental needs.

The illumination sources will consist of white light, laser light, and collimated laser beams. The illumination sources provided will be at a light intensity level at the test cell compatible with the sensitivities of the selected cameras required by science. The light from each source will be transmitted to the experiment through an optical fiber; each fiber will have an industry standard optical fiber interface which is accessible from the front of the Fluids rack. The use of fiber optics also helps isolate the test cell from the heat that the light source generates. The exceptions to this are PI-provided diode lasers, which may be integrated with the experiment but will be powered by the facility-provided diode drivers

The facility will provide white light sources (halogen bulbs) in order to meet the requirement for acquiring color images as well as the requirement for preventing "ringing" in the image caused by light that is highly coherent. The facility will provide a range of light intensities, between 0.01 mW/cm2 and 0.3 mW/cm2, at a 10 cm by 10 cm area test cell. The white light sources will be delivered via an optical fiber to a woven fiber backlight which will provide uniform lighting while requiring only minimal volume. In addition, an LED array will be provided for short exposure times or high-frame rate imaging, as well as continuous backlighting. The LED array will illuminate the test cell directly by being positioned on the optics plate.

In addition to the white light sources, the facility will provide six lasers. The FIR provided lasers consist of a Nd:YAG, HeNe, and two pairs of laser diodes with associated driver modules. The Nd:YAG is a high quality, diode-pumped, solid state laser whose wavelength is 532 nm with a laser power of at least 60 mW from the optical fiber. The Nd:YAG beam will provide a laser suitable for critical applications, as well as sufficient power to illuminate relatively large test cell areas. A 1.0 mW single mode HeNe laser (633 nm is linearly polarized with a polarization ratio of greater than 500:1) will provide low-power laser light suitable for critical applications such as interferometry. The HeNe's laser output beam power is fixed, requiring the user to optically attenuate the beam at the output

Two pairs of laser diodes are available for illuminating large test cell areas when the beam structure is not critical. These laser pairs have a wavelength of 680 nm and 770 nm with a linewidth of less than 0.15 nm. The power delivered by each of these lasers is at least 10 mW at the test cell. The diode lasers output intensities can be attenuated by lowering their drive currents to accommodate a wide range of needs. Four well-conditioned power supply modules (diode drivers) will be provided in order to support the FIR laser diodes and PI-provided diode lasers. This allows the FIR to accommodate some PI-specific requirements which are not met by the facility-provided lasers.

Environmental Control Subsystem: The Environmental Control Subsystem (ECS) performs thermal control, fire detection, fire suppression, and gas distribution functions associated with the operation of the FIR. The FIR's thermal energy is removed directly through thermal transfer to water or indirectly through a forced convection air system. The thermal subsystem will be designed to remove up to 2.0 kW of waste thermal energy from the Fluids Integrated Rack.

The thermal control subsystem consists of a distributed network of plumbing to carry supply and return water flow to and from the FIR hardware, including the air-to-water heat exchanger at the top of the ISPR. The heat exchanger removes waste thermal energy (nominally 1500 Watts) using the ISPR internal atmosphere as the medium for thermal energy transfer. This is the main vehicle for removing bulk heat from the FIR. Air-cooled packages will be supplied with cooling air ranging from 30˚ C (86˚ F) to 43˚ C (110˚ F). It is anticipated that the PI Unique H/W cooling will be approximately 400 W of air cooling with the option of using two 200 W Cold Plate(s) integrated into Optics Plate. The heat exchanger package consists of a set of impeller fans driving hot air over the air/water heat exchanger which includes air filtration (~300 micron) to remove the bulk of particulates that infiltrate into the airstream. The fans provide generic air flow down the front of the optic bench, though the IOP and under the plate and up the back, thus cooling the packages in the air stream. For components requiring a precise control of temperature, thermoelectric coolers, localized fans and or heat sinks will be used.

The gas distribution package provides access to ISS gaseous nitrogen, vacuum exhaust, and vacuum resource services through an interface panel. A convenient location for the FIR interface panel is currently being evaluated. The panel will provide one quick disconnect for each resource. Flexible umbilicals will be used to interface with experiment specific hardware.

Operations & Telescience: The FIR is being designed to minimize the crew time involved in reconfiguring diagnostics and setting up the specific experiments. Scheduled maintenance will be required of the ISS crew to recalibrate or replace sensors, replace or clean filters, and replace end-of useful-life components. It is not anticipated that on-orbit repairs will be performed, instead Orbital Replacement Units (ORU) will be transported to ISS or taken from on-orbit stowage. Stowage will be provided for science research on the ISS in passive rack locations for ORUs, science hardware, tools, etc.

During the performance of the PIs experiment the FCF will need to provide near-real-time data down-link and near-real-time command up-link to permit the PI to perform remote interaction with the experiment. The PI will need to be provided with adequate and timely data to react to unexpected scientific phenomena in order to alter the experiment procedures. The FCF will be teleoperated from the NASA Lewis Research Center Telescience Support Center. In concert with the Cleveland-based Operations Team, the Principal Investigator's experiment can be remotely monitored and controlled from the PI's homesite. The ISS crew will not be the primary FCF operators since they will have very limited time to dedicate to a specific facility due to their overall work load in day-to-day operations of the ISS. Instead, the ground team at the TSC and the PI at the remote site will monitor the health and status of FCF and the experiment and control facility functions.

B. FIR EXPERIMENT SPECIFIC HARDWARE

The FIR features the capability to remove and replace different PI specific experiment packages. The PI experiment specific package(s) may consist of a single self-contained unit and/or several separate components. The PI hardware will typically be a unique design, but may re-use hardware and designs from previous experiments. A set of similar experiments investigating common phenomena and/or using similar diagnostics may permit the development of a "mini-facility" that can accommodate multiple PIs to significantly lower overall PI development costs. The experiment package will typically consist of the fluids test cell(s), precision optical diagnostic instrumentation (shearing interferometry, schlieren, surface profilometry, etc.) that interface with FIR services previously discussed, and any support equipment such as injection & mixing devices, motors, critical temperature hardware, magnetic field generation not provided by the FIR.

A number of investigation specific hardware packages are currently under development or are planned for development and are listed below as typical examples of FIR experiment specific hardware.

1. <u>Suspension Research Apparatus.</u> A couette cell is being developed to study the flow of bubbly suspensions. The couette device is 30 cm high, with an outer cylinder diameter of 30cm and gap-thickness of 3 cm. The outer cylinder is capable of rotating at variable speeds (up to 100 rpm), while the inner cylinder remains stationary. Bubbles are introduced into the couette cell at gap-averaged volume fractions ranging from 0.1 to 0.2. The bubble diameters vary from 2 to 3 mm and are uniform within 10% of the mean bubble radius. The instrumentation consists of hot wire probes to measure liquid velocity and the bubble collision rate, wall shear stress probes, and photography to visualize the flow cell.

2. <u>Light Microscopy Module (LMM).</u> The LMM is currently under development for several colloid science investigations. The LMM will include a fully remotely-controlled, up-right microscope containing a video microscopy system that includes variable magnification optics, video camera, and color illumination sources. The system will be capable of resolving down to 0.5 micron structures within thin cell samples of approximately 100 microns thick. The LMM will also be employing light scattering techniques (Bragg, Dynamic Light Scattering, Static Light Scattering) to provide data on crystal growth and dynamics. The means for handling multiple samples will be included, to permit sample manipulation and change-out of test samples. The sample system will also contain a homogenizer to provide for a homogenous sample before the growth cycle begins. A confocal optics attachment may be included to improve resolution of the focal plane and to aid in the construction of 3-D imaging of the crystalline structures. The use of LASER Tweezers during real-time operations to manipulate and capture sample particles to affect crystal growth possibly may be included.

3. <u>Granular Flow Apparatus.</u> A shear cell is being developed to study an aspect of particle segregation important in reduced gravity. In this device, bumpy frictional boundaries in an oval channel will be used to control the energy of particle velocity fluctuations in the fully-developed flow in the straight sections. The device is approximately 34 inches long, 9.5 inches wide and 6.6 inches high. Cross section of the flow area is about 2.5 cm. by 4 cm. The outer boundary is stationary, while the inner

boundary is capable of being driven at speeds up to at least 1 meter/second. Various material and size particles can be used. The instrumentation consists of temperature, tachometer and acceleration probes, as well as photography to visualize the flow at a window located along the straight section.

4. Contact Line Dynamics Apparatus. A flight instrument to conduct steady state moving contact line experiments is under development. The hardware utilizes a mechanical system to drive a 2 cm diameter solid rod through a liquid free surface at several velocities to create a smoothly moving contact line. An optics system allows visualization of the three phase interface along with the associated fluid motion. A variety of test surfaces and fluids are possible. Special precautions are being taken to insure the cleanliness of the surfaces and fluids. Although each module is being designed to conduct a test with a single fluid, multiple modules may be employed which rely on a common plumbing and support structures. The instrument may be adaptable to other types of contact line experiments.

5. Foam Experimentation Apparatus. A cone and plate geometry cell is being developed for research on aqueous foams. The cone and plate radius is 10 cm, with a cone angle of 0.2 radians and gap thickness varying from zero to two centimeters. The plate remains stationary while the cone rotates at up to 143 rpm. The cone and plate materials are nonwetting, and their inner surfaces are roughened in order to provide a no-slip condition, while the outer surfaces are of optical quality. The sidewall is nonwetting, and optically smooth on the inner and outer surfaces in order to provide a slip condition and to permit access for video microscopy. The apparatus will produce foam samples of variable liquid content and chemical composition in sufficient quantity to fill the sample cells (approximately 100 ml). The instrumentation consists of video microscopy to image the gas bubbles at the inner surface of the sidewall, a rheometer to measure shear deformation throughout the foam sample, and diffusing-light spectroscopy to analyze the nature and time scales of bubble motion.

6. Magnetorheological Fluids Apparatus. An apparatus is currently under development to study rheology pattern formation and phase transitions of magnetorheological fluids with various volume fractions. The system is capable of generating a fluid of specified volume fraction and delivering it to a sample cell. The sample cell is used as the test volume for parallel plate rheometry which is used to develop uniform structures. The parallel plate gap size is adjustable between 5 micron and 10 mm. A magnetic field source is applied to the sample height. It can provide both a step increase to 1000 gauss over a period of 10 hours and also the quick ramp increase to 1000 gauss in 10 milliseconds. The apparatus provides for transmission of laser light through the two parallel plates, as well as through the container walls. Instrumentation consists of a parallel plate rheometer which provides a constant strain rate and measurement of the resulting stress, static laser light scattering to study the equilibrium macro structure, and video microscopy to view the micro structure.

7. Pool Boiling Apparatus. An apparatus suitable for a variety of pool boiling investigations is being developed. It consists of a pool boiling chamber, with an envelope measuring 35 cm x 35 cm x 75 cm, several imaging cameras and light sources, a nitrogen fed pressure control system and bellows, a stirrer, a smooth silicon surface over a microheater, and cooling system. A computer controller is used to regulate the temperature of the boiling surface and the bulk fluid. The temperatures in the pool, as well as on the backside of the silicon wafer are measured using thermocouples. The variation of the temperature in different parts of the pool held to within ±0.2°C of the mean temperature. The system pressure above the liquid pool is measured with an accuracy of ±0.5 kPa. The hardware has a video imaging system that will operate at a frame rate of 10-50 fps. The addition of a holographic interferometer for temperature distribution measurements around the bubble is being contemplated.

C. NASDA FLUID PHYSICS EXPERIMENT FACILITY (FPEF)

The Fluid Physics Experiment Facility (FPEF) is being developed by National Space Development Agency of Japan (NASDA) for the Japanese Experiment Module (JEM) of the International Space Station. The FPEF is a multi-user facility and designed to perform fluid physics experiments in an ambient temperature environment. The FPEF consists of a main body and an experiment section, and occupies a quarter-rack of the JEM. The experiment section will be configured to satisfy the needs of individual experiment. The overall dimensions of the experiment cell are 350 mm (W) x 350 (D) x 300 (H). The maximum electric power available is 978 watts. Currently, thermocapillary flow research in a liquid bridgs is used as a model experiment for the FPEF design. Several diagnostic techniques are being developed for the experiment. The capability of the FPEF for thermocapillary flow research is summarized below.

The FPEF can perform three-dimensional, in-situ observation of tracer particles in a transparent liquid column. It can also measure the fluid velocity by the UVP (Ultrasonic Velocity Profile) technique. The photochromic dye activation method can be applied to determine the free surface velocity accurately, which has not been done in past thermocapillary flow experiments. An infrared imager can measure the free surface temperature. It is being discussed to design a new experimental cell that deals with liquid bridges of molten materials with relatively low melting points, up to about five hundred degrees centigrade. Such an experiment has not been performed in microgravity.

The experiment section and the observation and measurement systems of the FPEF are exchangeable. Various experiments, such as bubble generation and behavior, heat transfer, liquid wettability, and combustion experiments, will be performed in the FPEF.

D. ESA FLUID SCIENCE LABORATORY (FSL)

The European Space Agency (ESA) is developing the Fluid Science Lab (FSL) to be operated in the Columbus Orbital Facility (COF) of the International Space Station (ISS). FSL provides the interfaces for a thermally controlled environment to perform experiments in the field of fluid physics, i.e. experiments with optically transparent media. The FSL is therefore equipped with a large standard set of advanced optical diagnostics, especially different types of interferometers. FSL is an upgrade of a previous ESA developed fluids facility -- the Bubble Drop Particle Unit. As with BDPU, the FSL supports scientific microgravity research in the many fields of fluid physics. Phenomena can either be observed inside transparent media or on opaque surfaces. Examples of these types of investigations are, but not necessarily limited to the areas of: hydrodynamic behaviors of fluid systems; phase interface behaviors of non-equilibrium fluid systems; surface deformations and oscillations of fluid bridges; nucleation and condensation phenomena in over-saturated and sub-cooled liquids; and critical point phenomena. Examples of new areas are: Aerosol/Colloid Research, Plasma Crystals and Solution/Gel Crystal Growth.

Facility Design: Given the long-term operations and multiple access opportunities in an ISS environment, the FSL concept emphasizes reusable multi-user capability with a high high degree of modularity at both the facility and individual test container levels. Functionally self-contained modular units will facilitate servicing and maintenance operations. The basic facility integrates functional and operational subsystems into one six-post double wide International Standard Payload Rack (ISPR). The facility-provided functions include: power conditioning and distribution; command and data handling; various modes of experiment processing; video/imaging management; active alignment of interferometric diagnostics; active thermal control; and vacuum / vent interfaces. The facility provides up to 3 kW of power and about 400 W of thermal rejection capability for the Experiment Test Containers and about 1200 W for all other components.

The heart of the facility is the Facility Core Element (FCE), which includes the Optical Diagnostics Module; Central Experiment Modules 1 (microgravity measurement assembly, the experiment test container as well as supporting optical equipment) and 2 (other supporting optical equipment and electronics). Other FSL components include: the Master Control Unit, the Power Control Unit, the Video Management Unit, laptop computer and thermal control equipment.

Facility Diagnostics: Optical diagnostics are housed in the Facility Core Element. During experiment operations the FCE will be detached from the rack. This supports a precise stable alignment and minimizes possible distortions by external loads. The maximum field of view of the standard diagnostic tools is 80 x 80 mm. The two observation directions are perpendicular. White and monochromatic background, sheet and volume illumination are provided. Various optical diagnostics capabilities are available simultaneously or quasi simultaneously. Due to the opto-mechanical design there are 53 simultaneous "pair applications" possible with about 10 diagnostic tools. Diagnostics include: Particle Image Velocimetry, Photogrammetric Particle Tracking, Electronic Pattern Speckle Interferometry for transparent and surface deformation measurements, Holographic and Differential Interferometry, Schlieren Measurements. Recording of images is possible with: analog and digital electronic monochrome cameras with different spatial and time resolution. There is an interface for quantitative color measurements with 3 Chip RGB cameras. There are means to perform telescience with a maximum digital data downlink rate of about 2 Mbit/sec and a maximum digital rate of image data of about 240 Mbit/sec can be recorded in realtime for about 17 minutes. Variable realtime compression is also available for the recording of quantitative image data; this automatically extends the recording time by the applied compression factor. Interfaces will be provided for dedicated Front Mounted Cameras specializing in non-standard imaging functions such as infrared imaging and high speed/high resolution imaging. In place of the Front Mounted Cameras it is also possible to mount a traditional photographic film camera, utilized for extreme imaging requirements.

<u>Experiment Test Container (ETC):</u> The EC volume has been increased compared to the BDPU design. The experiment container volume will be about 450 x 270 x 280 mm. The maximum field of view of 80 x 80 mm is centered. The experiment container reflects the particular experiment requirements of the investigation. For example this may include such things as fluid containment (the fluid cell together with the whole fluid loop), fluid transfer and mixing equipment (injection, extraction, stirring), sensors (p,T), dedicated diagnostics such as LDA/LDV and dedicated electronics such as more accurate thermal conditioning.

<u>Facility Operations:</u> An autonomous control approach is used for housekeeping and experimental data set generation, transmission, displaying and storage. Command uplink and image downlink will be accommodated. Telemetry and telecommanding will be such as to neither disrupt continuous experiment processes nor to contribute to the loss of data. Minimal crew support is anticipated.

E. DISPOSITIF POUR L'ETUDE DE LA CROISSANCE ET DES LIQUIDES CRITIQUES (DECLIC)

DECLIC is a new, modular, multi-user facility currently being designed and built by the French Space Agency, CNES for use aboard the International Space Station, initially in the US Laboratory followed by the Japanese Experiment Module, the Columbus Orbital Facility or the Russian module. The facility is being designed to conduct microgravity investigations in critical phenomena and directional solidification of transparent alloys.

Specifically, DECLIC will accommodate chemical-physical studies of supercritical pure fluids with a critical temperature lower than 100°C and a critical pressure lower than 100 bar such as CO_2, SF_6 and Xe, and supercritical pure fluids and solutions with a critical temperature lower than 600°C and a critical pressure lower than 500 bar such as H_2O and aqueous solutions. It will also accommodate microgravity investigations in morphological stability at the solid/liquid interface during crystal growth in transparent alloys. In addition, investigations in condensed matter physics requiring a long term microgravity environment can also take advantage of the capabilities offered by DECLIC.

DECLIC is the follow-on to the ALICE-2 facility, still onboard the Russian MIR space station, but will accommodate wider classes of experiments. The facility provides advanced optical diagnostics, including wide field imaging, microscopy, interferometry and small angle light scattering as well as highly accurate measurements of thermophysical parameters (pressure, temperature). All experiments can be conducted within a very stable and accurately thermally controlled environment. Operation of the facility is via quasi real-time telescience.

More detailed information about DECLIC and its capabilities can be obtained at the CNES web site:

http://www.cnes.fr/espace_pro/declic/declic.html

F. TWO-PHASE FLOW FACILITY (TPFF)

The TPFF is a proposed external facility on the International Space Station being planned by the Lewis Research Center. The TPFF will be suitable for the characterization of flow regimes, flow-regime transition and phase change (boiling and condensation) in extended-duration microgravity. The facility will be designed to accommodate experiments that require long runs of straight tube, typically greater than 100 tube diameters or a 5 meter long test section for 5 cm diameter tube. This size limitation generally makes these types of experiments unsuitable for the FIR or other pressurized areas on the station. The facility will provide data on heat transfer, pressure drop, and flow-stability boundaries for use in developing predictive frameworks that are currently lacking.

G. PHYSICS OF COLLOIDS IN SPACE APPARATUS (PCSA)

The PCSA apparatus is under developed at the Lewis Research Center to study colloidal phenomena in the microgravity environment of the International Space Station. The apparatus can study fractal phenomena, growth of super-lattice structures from binary (two-component) solutions of hard-sphere colloidal particles, and behavior of polymer-colloidal mixtures (e.g. depletion flocculation). The apparatus is not limited to these studies. It offers a much broader scope in studying a wide range of fundamental problems in colloid physics, physical chemistry, chemical physics, materials science, and biological fluids.

The PCSA provides four basic diagnostic measurements. These include non-invasive dynamic light scattering (DLS), static light scattering (SLS), Bragg scattering, and rheological measurements. The light scattering measurements are provided by two Nd-Yag lasers (maximum incident power of 40 mW) and either avalanche photo diodes or digital cameras for scattered light detection/measurement. In the PCSA, the DLS and SLS measurements can be performed at forward scattering angles of 11 to 169 degrees with a 0.1 degree increment resolution. The low angle light scattering measurements can be performed over forward scattering angles of 0.3 to 6.0 degrees with an imaging resolution of 0.01 degrees. Bragg scattering measurements can be performed over scattering angles of 10 to 60 degrees with an imaging resolution of 0.25 degrees. The apparatus also provides in-situ mixing of aqueous samples and sample images via two CCD color cameras (full sample view and magnified). Sample oscillations can be performed at an oscillation amplitude of 0.125 to 1.5 degrees at 0.02 to 20 Hz to support rheological measurements via DLS. All these measurements are made through an optical sample cell that has a cylindrical volume of 20 mm diameter x 10 mm high. The PCSA provides eight sample cells that are mounted on a carousel in order to rotate them in and out of the diagnostic stations.

The PCSA is accommodated in the ISS EXPRESS Rack, the first available research facility on the ISS. The PCSA provides for onboard data storage and data downlink. Operation is controlled via ground commanding with limited options for crew commanding. The apparatus provides for containment of the eight sample cells which prevents any crew interaction with the samples.

H. EXTENSIONAL RHEOLOGY INSTRUMENT

A flexible and adaptable scientific instrument that can accommodate various classes of non-Newtonian liquids is under development at the Lewis Research Center. For example, to perform direct unambiguous measurements of the uniaxial extensional viscosity of a viscoeleastic polymer solution, and to characterize systematically how this fundamental non-Newtonian material varies with time and imposed deformation rate.

The apparatus allows for the stretching of a freely suspended cylindrical column of fluid (Boger fluid) by gripping the column with a drive mechanism that imposes the correct kinematics, eliminating unwanted shear gradient in the fluid and generating an homogeneous uniaxial stretching flow. The column is supported by a fixed and a moving endplate. The stationary endplate will have a reducing diameter device to achieve a 4:1 reduction in endplate diameter during the stretch to minimize shear stresses in the fluid. The end plate of the column will have a very sensitive force transducer capable of measuring forces in the range of 1 to 1,000,000 dynes. Diagnostics include a digital particle image velocimetry system using CCD cameras and a laser light sheet to record fluid motion near the endplates and a two point flow-induced birefringence measurement system for non-invasive probing of the molecular level of stress generated by the extensional flow.

This apparatus is currently being developed for flight on a sounding rocket, although modifications can possibly be made to accommodate this hardware on the ISS Fluids/Combustion Facility.

I. MECHANICS OF GRANULAR MEDIA APPARATUS (MGMA)

The MGMA, developed by the Marshall Space Flight Center, will use the weightless environment of orbital flight to study the dynamics of soil columns confined by water under very low pressures of 1,300, 520, and 52 Pascals. Information to be examined will be load, deformation, and fluid pressure data gathered during testing, as well as changes in the soil structure, including the formation of shear bands and change in density.

The heart of the MGM apparatus is a set of three prismatic test cells, each containing a 7.5 cm in diameter by 15 cm sleeves of Ottawa F-75 banding sand, a natural quartz sand (silicon dioxide) with fine grains and little variation in size. The soil specimen, mixed with either air or water, is contained in a latex sleeve that is 0.3 mm thick and printed with a grid pattern so cameras can record changes in shape and position. The sample is held between a fixed and a movable plate driven by a stepper motor and is viewed by an array of three CCD cameras illuminated with banks of small light-emitting diodes. Each camera observes through a different side of the Lexan prism to provide full coverage of the specimen. The MGMA video control system electronically interleaves the images and delivers the video signal to a portable video recorder.

The stepper motor can be commanded, via a laptop computer, to drive the platen against the specimen in a cyclic manner at speeds of 35-1000 mm/hr. The latex sleeve will move with the sand so the grid pattern changes shape, thus revealing changes to the cameras. At the same time, additional air will be pumped into the specimen, and excess water will be removed from the jacket, to maintain specified test pressures.

J. GLOVEBOX

The overall philosophy of the Glovebox program is to provide the ability to conduct smaller, less complex science experiments or technology demonstrations in a microgravity environment in a faster, better, and cheaper manner. The hardware development cycle runs approximately 2-3 years. The Glovebox is intended to be used a generic platform for conducting a wide range of experiments. It is especially well suited for experiments that require containment of materials, both fluid and solid. Experiments developed for the Glovebox are expected to be relatively small and self-contained yet can be of a sophisticated nature using state of the art diagnostics. Various services are available in the Gloveboxes including power, video, still photography, a laptop computer for experiment control and data acquisition, and cleaning supplies. In general these experiments are less automated and require significant crew involvement in their operation and in the scientific decision making process. At this time, 12 Glovebox Investigations in the disciplines of materials science, fluid physics, biotechnology, and combustion science are under development. Several versions of Gloveboxes have been flown on the Shuttle

Spacelab and Middeck as well as the Russian Mir Space Station. A Microgravity Science Glovebox for the International Space Station is currently under development.

The Middeck Glovebox (MGBX) facility is an enclosed volume that provides physical isolation of various experiments from the middeck and enables crew member manipulation of these experiments through gloveports. The MGBX provides containment of powders, splinters, liquids, flames, or combustion products which may be produced from experiment operations. The MGBX occupies two standard lockers in the space shuttle middeck. The MGBX door opening to insert or retrieve experiment hardware is about 20.3 cm by 19.4 cm. The working volume is about 35 liters and is approximately 45 cm wide, 30 cm deep, and 25 cm high.

An air filtering system protects the middeck environment from experiment products. Forced air cooling can withdraw a maximum of 60 watts of experiment generated heat. Up to 60 watts of experiment power can be provided via a protected 28 VDC line. A power converter box is also available which can provide +24, +5, +12, and -12 VDC lines.

The MGBX can be used in various modes of pressure and air circulation. The working area can serve as a sealed environment that is isolated from the crew cabin atmosphere, as a constantly recirculating atmosphere that is maintained at a pressure slightly lower than the middeck ambient, or as a working area open to the middeck. Airtight gloves or non-sealed cuffs are mounted in the two gloveports. Multipurpose filters remove particles, liquids, and reaction gases from the recirculated air. Pressure, humidity, and temperature sensors are utilized to monitor filter performance.

Video and 35 mm cameras are the primary method utilized for gathering data. The MGBX has three CCD video cameras. The camera control electronics are contained within the MGBX, while the camera heads can be mounted external to the MGBX and positioned to view through the specialized video ports, or through the large window on top of the MGBX. The videoports allow the camera heads to swivel to view the entire working area. Both black and white and color videocameras are available. Three video recorders provide data storage, with digital data stored in the audio channels (up to three audio and three discrete channels of data can be recorded). Due to limitations of the Space Shuttle middeck, there is no standard data or video downlink. There is the possibility of some near real-time video downlink (from the Shuttle Camcorder), but this will be determined on a mission-by-mission basis. Adjustable lighting, video port plugs, a backlight panel, a halogen flashlight, and a stray light window cover provide different photographic options.

The ISS Microgravity Science Glovebox (MSG) will be a larger version of the Middeck Glovebox, is under development by the European Space Agency, and will be available for use soon after the deployment of the US Laboratory Module of the ISS.. The MSG will have a larger work area to allow larger size and mass experiments to be conducted inside the Glovebox. The MSG will provide up to 1000 watts of experiment power, a vent connection, a nitrogen connection, an airlock, illumination, color and black and white video cameras and recorders for viewing, recording, or downlinking, and miscellaneous tools and cleaning supplies. It is envisioned that experiments will be conducted in the areas of fluid physics, combustion science, materials science, and biotechnology.

K. GLOVEBOX EXPERIMENT HARDWARE

1. <u>Glovebox Laser Light Scatterer.</u> A compact instrument has been designed that is capable of both static and dynamic light scattering. This instrument was designed to operate in the various versions of the Glovebox facility and occupies the volume of an 8" cube. It accepts cylindrical test cells with an outer diameter of 10 mm. A translation motor enables interrogation of a 2 cm length of a test cell with a translation velocity of either 24 μm/sec or 0.6 mm/sec. It is equipped with a pigtailed laser diode which delivers approximately 6-8 mW of power at 780 nm to the test section. A fiber optic pickup at 90° delivers scattered light to an avalanche photodiode detector. A Glovebox facility camera can be positioned to

record static light scattering data incident on a semi-cylindrical diffuse screen (approximately 30°-160°). Test samples can be oscillated about the cell axis with a fixed 1° or 2° amplitude. The instrument is capable of inducing single impulses or sinusoidal oscillations with variable frequency (1-16 Hz). The samples may also be rotated at variable speeds ranging from 0.3 - 3.0 rpm. The instrument is controlled via software resident in a laptop computer which also contains a digital correlator card to compute the temporal autocorrelation function from the avalanche photodiode output.

2. Heat Transfer Research Apparatus. A system is being designed perform research on the transport characteristics of passive change of phase heat transfer systems in microgravity and will be accommodated in the Microgravity Science Glovebox (MSG) on the International Space Station (ISS). The MSG will provide power, downlink and uplink capability, and containment.

A test module houses a number of cuvettes, partially filled with the working fluid. Each is outfitted with a pressure transducer and thermocouples. A heater is located at one end of the cuvette and a cooler at the other end. The heater and cooler create a heat flow through the cuvette and are controlled via computer. The thermocouples are used to calibrate the images from an infrared camera which provides the temperature profile along the length of the cuvette. Other optical diagnostics available are a microscope (50x), illumination system for the microscope, microscope camera, and macro camera. The macro camera will provide the gross shape of the liquid-gas interface. The images from the video are stored digitally. The instrument can also measure liquid film thickness in the cuvettes. The microscope has the ability to translate along the test module. An electrical system includes a frame grabber board for capture of the video images, storage for digital data, and controllers for the heater/cooler, translation table, and camera focus.

3. Typical Fluid Physics Glovebox Experiments:

a) Oscillatory Thermocapillary Flow Experiment (OTFE) is used to study surface tension driven flows in cylindrical geometries.

b) Interface Configuration Experiment (ICE) explores certain aspects of liquid/vapor interface behavior, primarily the uniqueness of certain mathematical predictions of fluid configurations in the absence of gravity.

c) Colloidal Disorder-Order Transitions (CDOT) uses colloidal suspensions of microscopic solid plastic spheres as a model of atomic interactions, using laser light scattering.

d) Binary Colloidal Alloy Test (BCAT) investigation will conduct fundamental studies of the formation of colloidal superlattices and large scale fractal colloidal aggregates/gels.

e) Colloidal Gelatin (CGEL) investigation is to conduct fundamental studies of the formation and structure of colloidal superlattices, large scale fractal colloidal aggregates and colloid-polymer mixtures by investigating the physical properties and dynamics of these formations.

f) Angular Liquid Bridge (ALB) investigation is to observe the discontinuous behavior phenomena for liquid bridges including the shape and stability of angular liquid bridges, the rate of spreading of liquid in a wedge vertex, the corner discontinuity for interfaces on interior corners, and the effects of hysteresis on the predicted discontinuous behaviors.

g) Capillary Heat Transfer (CHT) investigation is to gain an improved understanding of the mechanisms leading to unstable operation of and failure of capillary pumped heat transfer devices in low gravity and demonstrate that instabilities with an evaporating meniscus are responsible for unreliable operations.

h) Internal Flows in a Free Drop (IFFD) investigation observes internal flows in a radiantly heated, acoustically levitated drop.

II. GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced gravity research facilities that support the MRD fluids program include two drop towers at the Lewis Research Center (LeRC), and an evacuated drop tube at the Marshall Space Flight Center (MSFC), and parabolic flight research aircraft. A variety of specialized test rigs have been constructed and used to conduct a wide range of microgravity fluid physics research. In general these rigs have been developed to accommodate specific individual investigator's requirements. In addition, other capabilities have been developed which have the potential for use by multiple investigators/investigations. These include: two-phase flow test rigs, a computational lab, complex fluids cell flight hardware lab, and quench furnace with x-ray. In general, these facilities provide a variety of capabilities which investigators can select to support their series of experiments.

A. 2.2-SECOND DROP TOWER

The 2.2 Second Drop Tower is a heavily utilized reduced gravity facility at the Lewis Research Center that plays a key role in the support of Microgravity Science. It routinely supports over 1000 test drops per year (the daily test schedule allows up to 12 drops). The facility consists of a shop for experiment buildup, integration and testing; several small laboratories for experiment preparation and normal gravity testing; electronics support rooms and an eight story tower in which the drop area is located.

The Drop Tower at LeRC provides 2.2 second of low gravity test time for experiment packages with payload weights up to 139 kg. Rectangular experiment packages are dropped under normal atmospheric conditions from a height of 79 ft. Air drag on an experiment is minimized by enclosing it in a drag shield. A gravitational acceleration level of less than 10^{-4} g is obtained during the drop as the experiment package falls freely within the drag shield. The only external force acting on the falling experiment package is the air drag associated with the relative motion of the package within the enclosure of the drag shield. A drop is terminated when the drag shield and experiment assembly impact an air bag. The deceleration levels at impact have peak values of 15 to 30 g.

Data can be acquired by high-speed motion picture cameras as well as video cameras. Video signals are transmitted to remote video recorders via a fiber optic cable that is dropped with the experiment. Onboard data acquisition and control systems also record data supplied by instrumentation such as thermocouples, pressure transducers, and flowmeters.

B. 5.18-SECOND ZERO-GRAVITY FACILITY

The 5.18-second Zero-Gravity Facility at the Lewis Research Center has a 132 meter free fall distance in a drop chamber which is evacuated by a series of pumpdown procedures to a final pressure of 1 Pa. Experiments with hardware weighing up to 300 kilograms are mounted in a one meter diameter by 3.4 meter high drop bus. Gravitational acceleration of less than 10^{-5} g is obtained. At the end of the drop, the bus is decelerated in a 6.1 meter deep container filled with small pellets of expanded polystyrene. The deceleration rate ramps up to 65 g (in 150 milliseconds). Visual data is acquired through the use of on-board, high-speed motion picture cameras and 8mm video recorders. Also, other data such as pressures and temperatures are recorded on board with various data acquisition systems. Deceleration data are transmitted to a control room by a telemetry system. Due to the complexity of drop chamber operations and time required for pump-down of the drop chamber, only one or two tests are performed per day.

C. 105 METER DROP TUBE

A 105 meter long by 25 centimeter diameter drop tube located at the Marshall Space Flight Center provides 4.6 seconds of low gravity process time. The facility, primarily intended for containerless processing applications, can maintain a vacuum level of 10^{-6} torr or can be backfilled with various gases to increase cooling rates. Two heating methods are currently available, an electron-beam furnace and an electromagnetic levitator. Other heating methods are possible. Samples are viewed through ports located at eight meter intervals in the tube. The drop tube has been used for the study of undercooling, nucleation, and solidification phenomena in molten metal samples. However, the facility could also accommodate studies with ceramic or glass materials.

D. PARABOLIC FLIGHT RESEARCH AIRCRAFT

The parabolic research aircraft can provide up to 40 periods of low gravity for up to 25-second intervals each during one flight. The aircraft accommodate a variety of experiments of different sizes and is often used to refine space flight experiment equipment and techniques and to train crew members in experiment procedures, thus giving investigators and crew members valuable experience working in a weightless environment. The aircraft obtain a low gravity environment by flying a parabolic trajectory. Gravity levels twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth's gravity (10^{-2} g). The interior bay dimensions are approximately 3 meters wide and 2 meters high by 16 meters long. Several experiments, include a combination of attached and free-floated hardware (which can provide effective gravity levels of 10^{-3} g for periods up to 10 seconds) can be integrated in a single flight. Both 28 VDC and 100/115 VAC power are available. Instrumentation and data collection capabilities must be contained in the experiment packages.

E. TWO-PHASE FLOW TEST RIGS

Two gas-liquid flow loops exist that have been used to conduct testing aboard parabolic flight research aircraft at gravity levels of 0.01, 0.05, 0.17 (lunar), 0.33 (martian) and 0.50 g's are available. Both of these flow loops are blowdown types of systems whereby the liquid (water, a water-glycerin solution to ascertain the effects of the viscosity, and a water-surfactant solution to ascertain the effect of surface tension) and gas (air) are delivered from supply tanks to a collector tank via an instrumented test section. One flow loop can be used for testing with a 1.27 cm inner diameter test section, and the other flow loop can be used for testing with a 2.54 cm inner diameter test section. The liquid is recirculated between tests and the gas is vented into the aircraft cabin.

The air and liquid are metered into a mixer and flow into the test section that can be instrumented with conductivity probes, which necessitates the use of "conductive" liquids, differential pressure transducers and hot film anemometers. Data acquisition rates of up to 1000 Hz are possible. Photographic data can be recorded at rates of 250 or 500 full-field images per second or 500 or 1000 half-field images per second. Superficial gas velocities of 0.1 to 25 m/s and liquid velocities for 0.1 to 1.1 m/s are possible. Tests are conducted at atmospheric pressure. Adiabatic as well as sensible heat transfer tests can be conducted with the appropriately designed test sections.

F. COMPUTATIONAL LABORATORY

A laboratory for numerical modeling fluid flows as influenced by thermal gradients, concentration gradients, surface tension, magnetic fields gravitational acceleration, g-jitter, and other driving forces have been established at NASA Lewis Research Center. The emphasis is on physically based models giving quantitative flow descriptions. The laboratory has a combination of high-end UNIX workstations with extensive graphics support and an extensive selection of commercial, customized, and experiment-unique software, including most commercial CFD codes and also has access to mainframes as necessary. The laboratory and staff are available to funded investigators and their graduate students for consultation, analysis, and joint projects. It is recommended that potential lab services be discussed before submission to the NRA. Please call Arnon Chait, (216) 433-3558 or send e-mail to arnon.chait@lerc.nasa.gov

G. COMPLEX FLUIDS CELL FLIGHT HARDWARE LAB

This lab at LeRC has been used to build test cells for a variety of complex fluids instruments. The lab is capable of designing, building, filling, and 1-g testing optical cells for liquid-vapor critical fluid experiments. The cells are capable of operating from one to tens of atmospheres using pressurized glass and glass-metal cell construction with leak detection to 10^{-10} torr-liter/sec. Instrumentation including high relative precision (100 micro-K RMS) thermometry above and slightly below room temperature and high phase and spatial resolution full-field image phase shifting interferometry with seconds to days of stability are available. A variety of other light transmission, light scattering, and optical imaging tools are also available. The lab has high voltage AC and DC power supplies for 20-50 kV and zero to 75 kHz used in cells with millimeter size fluid gaps between electrodes. Acoustic experiments have been performed in liquid-vapor critical fluids employing continuous wave and pulse excitation and detection.

H. SLOWLY ROTATING BREADBOARD

The Slowly Rotating Breadboard is a 1 m long optical breadboard which rotates at 1-10 rpm, with the rotation axis offset 7 cm from the breadboard. The hardware is available for ground-based tests where gravitational settling can be circumvented via rotation. The apparatus was developed for the study of foams at high liquid content, but could be used for a variety of systems. In-situ diagnostics currently include diffusing wave spectroscopy at 532 nm and video microscopy. A slip-ring assembly allows electrical access during rotation. Future tests will incorporate the Slowly Rotating Breadboard with DC-9 parabolic flights. This will allow low-g testing, interrupted by periods of normal gravity during which the samples can be rotated.

I. MOTION ANALYSIS & OBJECT TRACKING SYSTEM (TRACKER)

The analysis of moving objects found in combustion and fluid science experiments has been made easier with the development of the Color Image Processing and Object Tracking System (Tracking System). The Tracking System is a personal computer-based collection of hardware and software that automates the tracking of objects previously recorded on film or videotape.

Typical features are as follows: Tracker is Pentium-Pro-based, uses a single monitor, and supports video devices and/or movie film transport. The input video devices currently supported are a Hi8 tapedeck, an S-VHS tapedeck, a laserdisk (Sony LVR-3000), and laserdisk (Panasonic - rewritable). In addition it also accepts digital images in tif, gif, tga, dxf, eps, img, jpeg, pcx, png, wmf, wpg, PhotoCD, and bmp formats. The tracker PC has a CD-RW drive (CD writer/player which records to a recordable or rewritable CD formats). The Tracker has software to grab sequences of images, digitize, and save them as digital files (tif, etc.) to hard disk, CD-RW drive, jaz drive, zip drive, floppy, or a network drive. Tracker can run on any Windows95 or NT computer, so it can be used to analyze previously saved digital image files.

Tracking methods supported include threshold reduction, template matching, and a spline-based active contour model method. The types of data obtained from Tracker are positions, velocities, area measurements, centroids, and outlines, all as a function of time.

III. <u>**MICROGRAVITY FLUID PHYSICS DIAGNOSTIC/MEASUREMENT CAPABILITY**</u>

NASA has adapted or developed a number of diagnostic/measurement techniques for microgravity fluid physics research which can be utilized for ground-based research and possibly modified for flight research. Techniques currently under development that are expected to become available in the near future or are currently available are described below.

A. SURFACE LIGHT SCATTERING HARDWARE

NASA's Advanced Technology Development (ATD) program is sponsoring the development of surface light scattering hardware. This instrument is designed to non-invasively measure the surface response function of liquids over a wide range of operating conditions while automatically compensating for gross surface motion. The surface response function can be used to compute surface tension, properties of monolayers present, viscosity, surface tension gradient, and surface temperature and its gradient. The instrument uses it optical an electronic building blocks developed for the laser light scattering program at NASA Lewis along with several unique surface light scattering components and new algorithms.

B. COMMON-PATH INTERFEROMETRY (CPI)

Because of a great need for measuring two-dimensional temperature and density distributions in transparent fluids used in many fluid physics experiments, the CPI is being developed and tested for some ranges of flow conditions. The CPI is a new, robust, compact, quantitative common-path interferometer that could use a low power HeNe laser as a light source. The instrument has a minimum number of optical components which can be used for ground-based and flight experiments, and it can be phase-stepped for high data-density recording. It can be easily converted into schlieren or shadowgraph instruments capable of handling a variety of fluid experiments. This includes real-time, steady, and non-steady fluid flow conditions.

C. STEREO IMAGING VELOCIMETRY (SIV)

A system of hardware and software has been designed to allow acquisition of three dimensional vectors describing flow simultaneously throughout an experimental volume. Used for ground-based and flight experiments, the quantitative results may be compared directly with numerical or analytical predictions of flow velocities. The system requires a transparent fluid seeded with particles large enough to be viewed as a full pixel on a video screen. Two synchronized orthogonal views provide the raw data. While generally used with light the algorithms for velocity vectors could also be used with x-ray images of suspended particles. The SIV system has worked for sample volumes between eight cc’s and two cubic meters. For experiments planned for the ISS the Fluids and Combustion Facility will contain orthogonal video cameras which can record the data required for three dimensional velocity analysis.

D. FORWARD SCATTERING PARTICLE IMAGE VELOCIMETRY

A technique for measuring three-dimensional particle position in a microscopic field-of-view has been developed at NASA Lewis Research Center. The technique relies on spatially sampling the forward scattered light from spherical objects using standard microscope illumination. A model has been developed which incorporates Mie scattering predictions with the optical response of a high numerical aperture microscope. The position of the particle along the optical axis (viewing direction) is determined by correlating the predicted and modeled scattering; a neural network has been used for the comparison. The technique has can offer high dynamic range along all three axes. Although the model predicts the response for any size sphere, the scientists have verified the predicts for micron size spheres.

E. BIREFRINGENCE MEASUREMENTS

A system for measuring flow-induced birefringence in a transient extensional flow has been packaged for microgravity experimentation. The system uses modulation techniques with AC detection and a single wavelength source to simultaneously measure the retardance and extinction angle in order to determine the conformation of polymer molecules. The apparatus also provides a simultaneous measurement of the diameter of the polymer solution. The system is being packaged for sounding rocket experiments and all components have passed rigorous alignment and vibration tests.

F. LASER FEEDBACK INTERFEROMETRY

Researchers at the NASA Lewis research center have developed a phase-shifted laser feedback interferometer and incorporated the instrument into a high numerical aperture microscope. The instrument can readily measure changes in the optical path length with nm precision and the microscope has transverse and axial resolution typical of a confocal microscope. Object or beam scanning is required to collect information over an area. The interferometer may also be used to measure vibrational amplitudes and is highly sensitive to changes in sample reflectivity.

G. DIFFUSING WAVE SPECTROSCOPY (DWS)

A compact instrument for Diffusing Wave Spectroscopy measurements has been built and tested on colloidal suspensions and foams. The instrument incorporates a frequency-doubled Nd:YAG laser with 100 mW output at 532 nm. Scattered light is detected using single-mode fiber optic probes, and the signal is analyzed by a high-speed digital correlator. Future testing using the DWS instrument will be done on the DC-9 aircraft, and it is expected to be available as a diagnostic instrument aboard the Space Station Fluids Integrated Rack.

H. ADDITIONAL TECHNIQUES

The following techniques are in already in use or currently under development:

1. Two dimensional particle imaging velocimetry
2. Rainbow Schlieren for measurement of temperature distributions
3. Light sheet flow visualization and/or velocimetry
4. Miniaturized laser doppler velocimetry
5. Liquid surface temperature and vapor phase concentration measurements via Exciplex Fluorescence

THE REQUIRED APPLICATION FORMS

MUST BE DOWNLOADED SEPARATELY FROM

http://peer1.idi.usra.edu/peer_review/nra/98_HEDS_03.html

INSTRUCTIONS FOR RESPONDING TO NASA RESEARCH ANNOUNCEMENTS

(JANUARY 1997)

A. General.

(1) Proposals received in response to a NASA Research Announcement (NRA) will be used only for evaluation purposes. NASA does not allow a proposal, the contents of which are not available without restriction from another source, or any unique ideas submitted in response to an NRA to be used as the basis of a solicitation or in negotiation with other organizations, nor is a pre-award synopsis published for individual proposals.

(2) A solicited proposal that results in a NASA award becomes part of the record of that transaction and may be available to the public on specific request; however, information or material that NASA and the awardee mutually agree to be of a privileged nature will be held in confidence to the extent permitted by law, including the Freedom of Information Act.

(3) NRA's contain programmatic information and certain requirements which apply only to proposals prepared in response to that particular announcement. These instructions contain the general proposal preparation information which applies to responses to all NRAs.

(4) A contract, grant, cooperative agreement, or other agreement may be used to accomplish an effort funded in response to an NRA. NASA will determine the appropriate instrument. Contracts resulting from NRA's are subject to the Federal Acquisition Regulation and the NASA FAR Supplement. Any resultant grants or cooperative agreements will be awarded and administered in accordance with the NASA Grant and Cooperative Agreement Handbook (NPG 5800.1).

(5) NASA does not have mandatory forms or formats for responses to NRA's; however, it is requested that proposals conform to the guidelines in these instructions. NASA may accept proposals without discussion; hence, proposals should initially be as complete as possible and be submitted on the proposers' most favorable terms.

(6) To be considered for award, a submission must, at a minimum, present a specific project within the areas delineated by the NRA; contain sufficient technical and cost information to permit a meaningful evaluation; be signed by an official authorized to legally bind the submitting organization; not merely offer to perform standard services or to just provide computer facilities or services; and not significantly duplicate a more specific current or pending NASA solicitation.

B. NRA-Specific Items. Several proposal submission items appear in the NRA itself: the unique NRA identifier; when to submit proposals; where to send proposals; number of copies required; and sources for more information. Items included in these instructions may be supplemented by the NRA.

C. Proposal Content. The following information is needed to permit consideration in an objective manner. NRAs will generally specify topics for which additional information or greater detail is desirable. Each proposal copy shall contain all submitted material, including a copy of the transmittal letter if it contains substantive information.

(1) *Transmittal Letter or Prefatory Material.*

(i) The legal name and address of the organization and specific division or campus identification if part of a larger organization;

(ii) A brief, scientifically valid project title intelligible to a scientifically literate reader and suitable for use in the public press;

(iii) Type of organization: e.g., profit, nonprofit, educational, small business, minority, women-owned, etc.;

(iv) Name and telephone number of the principal investigator and business personnel who may be contacted during evaluation or negotiation;

(v) Identification of other organizations that are currently evaluating a proposal for the same efforts;

(vi) Identification of the NRA, by number and title, to which the proposal is responding;

(vii) Dollar amount requested, desired starting date, and duration of project;

(viii) Date of submission; and

(ix) Signature of a responsible official or authorized representative of the organization, or any other person authorized to legally bind the organization (unless the signature appears on the proposal itself).

(2) *Restriction on Use and Disclosure of Proposal Information.* Information contained in proposals is used for evaluation purposes only. Offerors or quoters should, in order to maximize protection of trade secrets or other information that is confidential or privileged, place the following notice on the title page of the proposal and specify the information subject to the notice by inserting an appropriate identification in the notice. In any event, information contained in proposals will be protected to the extent permitted by law, but NASA assumes no liability for use and disclosure of information not made subject to the notice.

Notice

Restriction on Use and Disclosure of Proposal Information

The information (data) contained in [insert page numbers or other identification] of this proposal constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal the Government shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement). This restriction does not limit the Government's right to use or disclose this information (data) if obtained from another source without restriction.

(3) *Abstract*. Include a concise (200-300 word if not otherwise specified in the NRA) abstract describing the objective and the method of approach.

(4) *Project Description.*

(i) The main body of the proposal shall be a detailed statement of the work to be undertaken and should include objectives and expected significance; relation to the present state of knowledge; and relation to previous work done on the project and to related work in progress elsewhere. The statement should outline the plan of work, including the broad design of experiments to be undertaken and a description of experimental methods and procedures. The project description should address the evaluation factors in these instructions and any specific factors in the NRA. Any substantial collaboration with individuals not referred to in the budget or use of consultants should be described. Subcontracting significant portions of a research project is discouraged.

(ii) When it is expected that the effort will require more than one year, the proposal should cover the complete project to the extent that it can be reasonably anticipated. Principal emphasis should be on the first year of work, and the description should distinguish clearly between the first year's work and work planned for subsequent years.

(5) *Management Approach*. For large or complex efforts involving interactions among numerous individuals or other organizations, plans for distribution of responsibilities and arrangements for ensuring a coordinated effort should be described.

(6) *Personnel*. The principal investigator is responsible for supervision of the work and participates in the conduct of the research regardless of whether or not compensated under the award. A short biographical sketch of the principal investigator, a list of principal publications and any exceptional qualifications should be included. Omit social security number and other personal items which do not merit consideration in evaluation of the proposal. Give similar biographical information on other senior professional personnel who will be directly associated with the project. Give the names and titles of any other scientists and technical personnel associated substantially with the project in an advisory capacity. Universities should list the approximate number of students or other assistants, together with information as to their level of academic attainment. Any special industry-university cooperative arrangements should be described.

(7) *Facilities and Equipment.*

(i) Describe available facilities and major items of equipment especially adapted or suited to the proposed project, and any additional major equipment that will be required. Identify any Government-owned facilities, industrial plant equipment, or special tooling that are proposed for use. Include evidence of its availability and the cognizant Government points of contact.

(ii) Before requesting a major item of capital equipment, the proposer should determine if sharing or loan of equipment already within the organization is a feasible alternative. Where such arrangements cannot be made, the proposal should so state. The need for items that typically can be used for research and non-research purposes should be explained.

(8) *Proposed Costs.*

(i) Proposals should contain cost and technical parts in one volume: do not use separate "confidential" salary pages. As applicable, include separate cost estimates for salaries and wages; fringe benefits; equipment; expendable materials and supplies; services; domestic and foreign travel; ADP expenses; publication or page charges; consultants; subcontracts; other miscellaneous identifiable direct costs; and indirect costs. List salaries and wages in appropriate organizational categories (e.g., principal investigator, other scientific and engineering professionals, graduate students, research assistants, and technicians and other non-professional personnel). Estimate all staffing data in terms of staff-months or fractions of full-time.

(ii) Explanatory notes should accompany the cost proposal to provide identification and estimated cost of major capital equipment items to be acquired; purpose and estimated number and lengths of trips planned; basis for indirect cost computation (including date of most recent negotiation and cognizant agency); and clarification of other items in the cost proposal that are not self-evident. List estimated expenses as yearly requirements by major work phases.

(iii) Allowable costs are governed by FAR Part 31 and the NASA FAR Supplement Part 1831 (and OMB Circulars A-21 for educational institutions and A-122 for nonprofit organizations).

(9) *Security*. Proposals should not contain security classified material. If the research requires access to or may generate security classified information, the submitter will be required to comply with Government security regulations.

(10) *Current Support*. For other current projects being conducted by the principal investigator, provide title of project, sponsoring agency, and ending date.

(11) *Special Matters*.

(i) Include any required statements of environmental impact of the research, human subject or animal care provisions, conflict of interest, or on such other topics as may be required by the nature of the effort and current statutes, executive orders, or other current Government-wide guidelines.

(ii) Proposers should include a brief description of the organization, its facilities, and previous work experience in the field of the proposal. Identify the cognizant Government audit agency, inspection agency, and administrative contracting officer, when applicable.

D. Renewal Proposals.

(1) Renewal proposals for existing awards will be considered in the same manner as proposals for new endeavors. A renewal proposal should not repeat all of the information that was in the original proposal. The renewal proposal should refer to its predecessor, update the parts that are no longer current, and indicate what elements of the research are expected to be covered during the period for which support is desired. A description of any significant findings since the most recent progress report should be included. The renewal proposal should treat, in reasonable detail, the plans for the next period, contain a cost estimate, and otherwise adhere to these instructions.

(2) NASA may renew an effort either through amendment of an existing contract or by a new award.

E. Length. Unless otherwise specified in the NRA, effort should be made to keep proposals as brief as possible, concentrating on substantive material. Few proposals need exceed 15-20 pages. Necessary detailed information, such as reprints, should be included as attachments. A complete set of attachments is necessary for each copy of the proposal. As proposals are not returned, avoid use of "one-of-a-kind" attachments.

F. Joint Proposals.

(1) Where multiple organizations are involved, the proposal may be submitted by only one of them. It should clearly describe the role to be played by the other organizations and indicate the legal and

managerial arrangements contemplated. In other instances, simultaneous submission of related proposals from each organization might be appropriate, in which case parallel awards would be made.

(2) Where a project of a cooperative nature with NASA is contemplated, describe the contributions expected from any participating NASA investigator and agency facilities or equipment which may be required. The proposal must be confined only to that which the proposing organization can commit itself. "Joint" proposals which specify the internal arrangements NASA will actually make are not acceptable as a means of establishing an agency commitment.

G. Late Proposals. A proposal or modification received after the date or dates specified in an NRA may be considered if doing so is in the best interests of the Government.

H. Withdrawal. Proposals may be withdrawn by the proposer at any time before award. Offerors are requested to notify NASA if the proposal is funded by another organization or of other changed circumstances which dictate termination of evaluation.

I. Evaluation Factors.

(1) Unless otherwise specified in the NRA, the principal elements (of approximately equal weight) considered in evaluating a proposal are its relevance to NASA's objectives, intrinsic merit, and cost.

(2) Evaluation of a proposal's relevance to NASA's objectives includes the consideration of the potential contribution of the effort to NASA's mission.

(3) Evaluation of its intrinsic merit includes the consideration of the following factors of equal importance:

(i) Overall scientific or technical merit of the proposal or unique and innovative methods, approaches, or concepts demonstrated by the proposal.

(ii) Offeror's capabilities, related experience, facilities, techniques, or unique combinations of these which are integral factors for achieving the proposal objectives.

(iii) The qualifications, capabilities, and experience of the proposed principal investigator, team leader, or key personnel critical in achieving the proposal objectives.

(iv) Overall standing among similar proposals and/or evaluation against the state-of-the-art.

(4) Evaluation of the cost of a proposed effort may include the realism and reasonableness of the proposed cost and available funds.

J. Evaluation Techniques. Selection decisions will be made following peer and/or scientific review of the proposals. Several evaluation techniques are regularly used within NASA. In all cases proposals are subject to scientific review by discipline specialists in the area of the proposal. Some proposals are reviewed entirely in-house, others are evaluated by a combination of in-house and selected external reviewers, while yet others are subject to the full external peer review technique (with due regard for conflict-of-interest and protection of proposal information), such as by mail or through assembled panels. The final decisions are made by a NASA selecting official. A proposal which is scientifically and programmatically meritorious, but not selected for award during its initial review, may be included in subsequent reviews unless the proposer requests otherwise.

K. Selection for Award.

(1) When a proposal is not selected for award, the proposer will be notified. NASA will explain generally why the proposal was not selected. Proposers desiring additional information may contact the selecting official who will arrange a debriefing.

(2) When a proposal is selected for award, negotiation and award will be handled by the procurement office in the funding installation. The proposal is used as the basis for negotiation. The contracting officer may request certain business data and may forward a model award instrument and other information pertinent to negotiation.

L. Cancellation of NRA. NASA reserves the right to make no awards under this NRA and to cancel this NRA. NASA assumes no liability for canceling the NRA or for anyone's failure to receive actual notice of cancellation.

APPENDIX D
NRA-98-HEDS-03

NASA RESEARCH ANNOUNCEMENT (NRA) SCHEDULE

MICROGRAVITY FLUID PHYSICS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 PM EST). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below:

NRA Release Date: .... November 23, 1998

Letter of Intent Due: .... January 15, 1999

Proposal Due: .... March 2, 1999

Submit Proposal to:

Dr. Gerald Pitalo
c/o Information Dynamics Inc.
Subject: NASA Research Proposal (NRA-98-HEDS-03)
300 D Street, S.W., Suite 801
Washington, D.C. 20024
Telephone number for delivery services: (202) 479-2609

Final Selections: .... September, 1999

Funding commences: .... No sooner than October, 1999
(dependent upon actual selection and procurement process)